TanDEM-X

Ground Segment

DEM Products Specification Document

EOC – Earth Observation Center

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DOCUMENT CHANGE CONTROL

This document is under configuration control. Latest changes to the document are listed first.

Issue	Date	Chapter	Changes
4.0		all	**Update for TanDEM-X DEM 2020**
			Format change from .doc to .docx
		2.2	Update of references
		4.2	New subsection: "Adopted acquisition plan for the TanDEM-X DEM 2020"
		4.4.2.2	New subsection: "Digital elevation model in orthometric/mean sea level heights (MSL)"
		4.4.3.5	Correction: all GeoTiffs are saved in big-endian byte order
		4.4.1 (old)	Section "TanDEM-X Intermediate DEM (IDEM)" and all its references have been deleted in this document, this product is not available any more
		4.4.4.1 (old)	Subsection "FDEM (Finer posting DEM)" and all its references have been deleted in this document, this product was never realized
		4.5.2.1	Subsection "HDEM (Finer posting DEM)" was updated, this product is available with a valid DEM proposal
		4.5.3	New Section "Specifics of TanDEM-X DEM 2020"
		A,B	Updated for TanDEM-X DEM 2020
3.2	25.04.2018		**Update for High resolution DEM (HDEM) DEMO Products**
		2.2	Update of references
		4.1	Update of HDEM description
		4.4.2	Meter values added in Table 11
		4.4.3	Update of FDEM and HDEM description
		B.2	Change log updated
		0	Updated GS project manager
3.1	28.07.2016	all	Minor updates in all chapters
		4.3.2	Change in the order of information layers. Updates for Figure 2 (DEM), 3 (HEM), 9 (inconsistencies), and 10 (COM) as well as description of COM
		4.4.2	Considering of error propagation factor for reduced DEM versions
		A, B	Renumeration of Chapter 5 and 6 to A and B (Appendix)
		A.2, B.1	XML parameter annotation update
		A.3	New section about product parameters for DEM quality added
		A.3.2	New subsection A.3.2 about quality remarks added
3.0	18.12.2013	4.3.2.2	Size of coherence estimation window (11 x 11 pixel) added
		4.3.2.5	Information about AMP calibration factor added for convertion to sigma_nought
		4.3.2.7	More detailed description added to the consistency mask (COM)
		4.3.2.9	The interpolation mask is omitted from the final TanDEM-X DEM. The former subsection 4.3.2.9 is moved to the IDEM section 4.4.1.1
		4.4	Section "Further DEM Products" renamed to "Specifics of DEM Product Variants"
		4.4.2	For DEM variants with reduced pixel spacing the WAM generation was changed from mode to maximum
		5.2.1	New section "Product parameters for DEM quality"
		6	New "Appendix II: Product change log" introduced

2.0	05.03.2013	 all 4.3.1.2 4.3.1.4 4.3.2 4.3.2 4.3.2.3 4.3.2.4 4.3.2.5 4.3.2.9 4.3.3.1 5	**Update for Intermediate DEMs** Major revision Coordinate system change: The center of the bounding corner pixels of a DEM tile are referring to integer coordinates for the latitude, and for the longitude Section 4.3.1 TanDEM-X DEM in 1- and 3- arcseconds pixel spacing moved to 4.4.2 Definition of add-on layers Equation 1 and 2 for DEM and HEM values of mosaicked pixels changed Shadow and layover flags are both based on a reference DEM and not on TanDEM-X data VOM (void mask) is re-named and extended to COM (consistency mask) Updated chapter of WAM New Amplitude mosaic (AM2) layer, representing a minimum amplitude value New file naming convention: exchanged order of latitude and longitude Appendix with selected annotation parameters and XML overview is added
1.7	28.09.2011	all	First public issue
1.0 – 1.6			Project internal issues

***<u>Note</u>*: Verify that this is the correct revision before use. Check the document server for the latest version.** *Hardcopies of distributed documents are not updated automatically.*

TABLE OF CONTENTS

1 Introduction

TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurement) opened a new era in spaceborne radar remote sensing [1]. In 2010 a single-pass SAR interferometer with adjustable baselines in across- and in along-track directions was established: by adding a second satellite TanDEM-X (TDX), an almost identical spacecraft to TerraSAR-X (TSX), a closely controlled formation was realized. With typical across-track baselines between 100 m and 500 m, a globally unprecedented, consistent Digital Elevation Model (DEM) has been generated from bistatic X-Band interferometric SAR acquisitions.

Beyond the generation of the global TanDEM-X DEM as the primary mission goal, there are a number of secondary mission objectives. These include the production of DEMs with even higher accuracies on a local scale as well as numerous other applications based on across- and along-track interferometry techniques. Furthermore, TanDEM-X supports the demonstration and application of new SAR techniques, with focus on multistatic SAR, polarimetric SAR interferometry, digital beam forming and super resolution.

The global DEM acquisition phase took four years: for the TanDEM-X DEM, data from December 12, 2010 to January 16, 2015 were composed. In order to reach the target accuracies, all land masses were covered at least twice in the same look direction, though with different baselines. The DEM processing of difficult mountainous terrain required further additional acquisitions from the opposite look direction allowing the filling of gaps caused by the oblique radar viewing geometry and resulting shadow and layover phenomena.

The TanDEM-X mission was financed and implemented as a public-private partnership between DLR and Airbus Defence & Space. DLR is responsible for the mission, ground segment design and implementation, mission operations, and the generation of the digital elevation model products. Airbus Defence & Space built the satellites and exclusively holds the rights for the commercial exploitation of the TanDEM-X DEM products. DLR serves and coordinates the scientific user community [I1], [I2].

The first TanDEM-X DEM product was finalized in 2016 and exceeds its initial specifications. The absolute height error, initially specified at 10 m accuracy (for LE90), offers with an approximate 2 m accuracy a five fold improvement and its coverage exceeds 99% [I20],[I21]. At this degree of accuracy, the Earth's surface is a highly dynamic system, which is particularly evident in the differences in height from various acquisition periods. Clear distinct signals in the X-band DEM are left by height changes in glaciers, permafrost regions and forests as well as infrastructure and agriculture.

Therefore, an additional complete coverage of the Earth landmass was captured to provide an independent unique DEM data set from a well-defined time span (2017-2020 mainly) to be used specifically for the assessment of temporal changes in comparision to the TanDEM-X DEM on a global scale. This new TanDEM-X DEM 2020 product benefits from improvements in the acquisition planning process and data processing enabling the achievement of reliable and highly accurate DEM data while using less acquisitions.

Chapter 4 introduces the main DEM products and their variants. The target accuracies are presented in Section 4.1. and the DEM generation process is summarized in Section 4.2. The DEM product specifications are briefly detailed in Section 4.3 which describes the accuracy and grid definitions (Section 4.3.1) and all information layers (Section 4.3.2). Information about the structure of the DEM product is provided in Section 4.3.3. Section 4.4. gives a short summary about the characteristics of the HDEM product and reduced posting variants. Section 4.5 describes the second global DEM product, the TanDEM-X DEM 2020. The Appendices contain an introduction to the eXtensible Markup Language (XML) schema, product parameters and change log information.

1.1 Purpose

The purpose of this document is to describe the mosaicked DEM products for the TanDEM-X mission, their specifications and formats. Not included here are the underlying interferometric SAR products, which are described in [I3].

1.2 Scope

This document reflects the current status of the DEM product specification for the TanDEM-X mission.

2 References

2.1 Applicable references

The following documents are fully applicable together with this document.

	Document ID	Document Title	Issue
[A1]	TDX-PD-RS-0001	TanDEM-X Mission Requirements Document (project internal)	Issue 4.0, 07.06.2011

2.2 Informative references

The following documents, though not formally part of this document, may clarify its' content.

	Document ID	Document Title	Issue
[I1]	TD-GS-PL-0069	TanDEM-X Science Plan, https://tandemx-science.dlr.de/ (accessed on December 6, 2010)	Issue 1.0 30.06.2010
[I2]	TD-GS-UM-0115	TanDEM-X Science Service System Manual, https://tandemx-science.dlr.de/ (accessed on Februar 1, 2013)	Issue 1.0 06.07.2010
[I3]	TD-GS-PS-3028	TanDEM-X Experimental Product Description, https://tandemx-science.dlr.de/ (accessed on Februar 1, 2013)	Issue 1.2 27.01.2012
[I4]	Rossi et al. 2012	Rossi, C., Rodriguez Gonzalez, F., Fritz, T., Yague Martinez, N., Eineder, M: TanDEM-X calibrated Raw DEM generation. ISPRS Journal of Photogrammetry and Remote Sensing, 73, pp. 12-20. DOI: http://dx.doi.org/10.1016/j.isprsjprs.2012.05.014, 2012.	2012
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[I8]	Huber et al., 2009	Huber, M., Wessel, B., Kosmann, D., Felbier, A., Schwieger, V., Habermeyer, M., Wendleder, A., Roth, A.: Ensuring globally the TanDEM-X height accuracy: Analysis of the reference data sets ICESat, SRTM, and KGPS-Tracks. Proceedings of IGARSS 2009, 12-17 July 2009, Cape Town, South Africa, pp. 769-772, 2009.	2009
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[I11]	Wessel et al. 2016	Wessel, B., Bertram, A., Gruber, Bemm, S.: A new high-resolution digital elevation model of Greenland derived from TanDEM-X. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XXIII ISPRS Congress Prague, pp. 1-8, 2016.	2016
[I12]	Gruber et al. 2016	Gruber, A, Wessel, B., Martone, M. and Roth, A.: The TanDEM-X DEM mosaicking: Fusion of multiple acquisitions using InSAR quality parameters. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 9(3), pp. 1058-1071. DOI: http://dx.doi.org/10.1109/JSTARS.2015.2421879, 2016.	2016
[I13]	TR8350.2	World Geodetic System 1984,	23.07.2004

		http://earth-info.nga.mil/GandG/publications/tr8350.2/tr8350_2.html (accessed on March 5, 2012)	
[I14]	Addendum to TR8350.2	"Addendum to NIMA TR8350.2: Implementation of the World Geodetic System 1984 (WGS84) Reference Frame G1150", http://earth-info.nga.mil/GandG/publications/tr8350.2/tr8350_2.html (accessed on December 6, 2010)	
[I15]	Ritter and Ruth 2000	Ritter, N. and Ruth, M.: GeoTIFF Format Specification GeoTIFF Revision 1.0, Specification Version 1.8.2, 2000	Issue 1.8.2 2000
[I16]	Just and Bamler, 1994	Just, D., Bamler, R.: Phase Statistics of Interferograms with Applications to Synthetic Aperture Radar, Appl. Optics, vol. 33, pp. 4361-4368, 1994.	1994
[I17]	MODIS, 2011	MODIS Overview, https://lpdaac.usgs.gov/lpdaac/products/modis_overview (accessed on January 28, 2011)	
[I18]	Lachaise and Fritz, 2016	Lachaise, M., Fritz, T.: Update of the Interferometric Processing Algorithms for the TanDEM-X High Resolution DEMs. In: Proceedings of EUSAR 2016, pp. 550-553. VDE e.V.; ITG. European Conference on Synthetic Aperture Radar (EUSAR), 2016-06-06 - 2016-06-09, Hamburg, Germany, 2016.	2016
[I19]	Wessel et al. 2016	Wessel, B., Breunig, M., Bachmann, M., Huber, M., Martone, M., Lachaise, M., Fritz, T. and Zink, M.: Concept and first example of TanDEM-X high-resolution DEM. In: Proceedings of EUSAR 2016, pp. 554-557. VDE e.V.; ITG. European Conference on Synthetic Aperture Radar (EUSAR), 2016-06-06 - 2016-06-09, Hamburg, Germany, 2016.	2016
[I20]	Rizzoli et al., 2017	Rizzoli, P., Martone, M., Gonzalez, C., Wecklich, C., Borla Tridon, D., Bachmann, M., Fritz, T., Huber, M., Wessel, B., Krieger, G., Zink, M.: Generation and Performance Assessment of the Global TanDEM-X Digital Elevation Model. ISPRS Journal of Photogrammetry and Remote Sensing, 132, pp. 119-139, Oct. 2017.	2017
[I21]	Wessel et al., 2018	Wessel, B., Huber, M., Wohlfart, C., Marschalk, U., Kosmann, D., Roth, A.: Accuracy Assessment of the Global TanDEM-X Digital Elevation Model with GPS Data. ISPRS Journal of Photogrammetry and Remote Sensing. 139, pp. 171-182, May 2018	2018
[I22]	NGA EGM Development Team	National Geospatial-Intelligence Agency (NGA) EGM Development Team: Earth Gravitational Model (EGM2008), released at https://earth-info.nga.mil/ (accessed on July 10, 2025)	
[I23]	González et al., 2020	González, C., Bachmann, M., Bueso-Bello, J.L., Rizzoli, P., Zink, M.: A Fully Automatic Algorithm for Editing the TanDEM-X Global DEM. Remote Sensing. 2020; 12(23):3961. DOI: 10.3390/rs12233961	2020
[I24]	TD-GS-PS-0215	González, C.: TanDEM-X 30m Edited Digital Elevation Model (EDEM) Product Description. HR, DLR, Oberpfaffenhofen, Germany, Public Document TD-GS-PS-0215, Issue 1.1, 2023. *[Online].* available at https://geoservice.dlr.de/web/dataguide/tdm30/ (accessed on July 10, 2025)	Issue 1.1, 2023
[I25]	Wessel et al., 2021	Wessel, B., Huber, M., Wohlfart, C., Bertram, A, Marschalk, U., Abdullahi, S., Georg, I., Roth, A.: TanDEM-X Polar DEM 90 m of Antarctica: Generation and Error Characterization of a filled and edited DEM, The Cryosphere, 15 (11), pp.5241 – 5260, https://doi.org/10.5194/tc-15-5241-2021, 2021	2021
[I26]	TD-GS-PS-0208	Huber, M.: TanDEM-X PolarDEM Product Description. EOC, DLR, Oberpfaffenhofen, Germany, Public Document TD-GS-PS-0208, Issue 1.6, 2022. *[Online].* available at https://geoservice.dlr.de/web/maps/tdm:polardem90:antarctica (accessed on July 10, 2025)	Issue 1.6, 2022
[I27]	TDM90	The TanDEM-X 90m Digital Elevation Model (data guide), released at https://geoservice.dlr.de/web/dataguide/tdm90/ (accessed on July 10, 2025)	

3 Terms, definitions and abbreviations

3.1 Terms and Definitions

Term	Definition
CE90	Circular error (90% confidence level): A threshold value of 90% of the absolute values of the discrepancies. In case of normal distributed discrepancies CE90=std.dev*1.645.
LE90	Linear error (90% confidence level): A threshold value of 90% of the absolute values of the discrepancies. In case of normal distributed discrepancies LE90= std.dev *1.645.
TanDEM-X DEM	First global DEM product of the TanDEM-X mission (2010 - 2015)
TanDEM-X DEM 2020	Second global DEM product of the TanDEM-X mission (2017 – 2022)
TanDEM-X FDEM	Finer posting DEM product of the TanDEM-X mission. This product was never realized.
TanDEM-X HDEM	High resolution DEM product of the TanDEM-X mission: On a local basis and special user request the G/S produces improved, high resolution DEMs. Additional DEM acquisitions were taken into account. The performance goal for a high resolution DEM is a relative height error in the order of 0.8 meter, and an independent pixel spacing of 6 meter.
TanDEM-X Intermediate DEM	Intermediate DEM (IDEM) product of the TanDEM-X mission derived from acquisitions of the first global coverage. IDEM products are no longer available as they are obsolete with the completion of the first TanDEM-X DEM.

3.2 Abbreviations

Abbreviation	Meaning
AM2	Amplitude mosaic representing the minimum value
AMP	Amplitude mosaic representing the mean value
COH	Interferometric coherence
COM	Consistency mask
COV	Coverage map
DEM	Digital elevation model
DEM2020	TanDEM-X DEM 2020 product, second global TanDEM-X DEM
DN	Digital number
EDEM	TanDEM-X 30m Edited Digital Elevation Model
EGM2008	Global Earth Gravitational Model
G/S	TanDEM-X ground segment
GCP	Ground control point
FDEM	Finer posting DEM
HDEM	High resolution DEM
HEM	Height error map
HoA	Height of ambiguity
IDEM	TanDEM-X Intermediate DEM product
ITP	Integrated TanDEM-X processor
ITRF	International terrestrial reference frame
KML	Keyhole markup language
LSM	Layover and shadow mask
MCP	TanDEM-X DEM mosaicking and calibration processor
MSL	Mean sea level
PU	Phase unwrapping
QA	Quality analysis
SAR	Synthetic aperture radar
SRTM	Shuttle Radar Topography Mission
SWBD	SRTM water body data
TanDEM-X	TerraSAR-X add-on for Digital Elevation Measurements

TDM	TanDEM-X mission
WAM	Water indication mask
WGS84	World Geodetic System 1984
XML	Extensible markup language
XSD	XML schema definition

4 DEM Products

The main product of the TanDEM-X mission is the TanDEM-X DEM that contains a global Digital Elevation Model (DEM) of the land masses of the Earth. The elevations are defined with respect to the reflective surface of X-Band interferometric SAR returns. Therefore, TanDEM-X DEM products predominantly represent a Digital Surface Model (DSM). Elevated objects are included but the heights might be affected by SAR inherent effects. For example, in forested areas the X-band SAR scattering center is located more in the upper part of the vegetation volume than on the crown itself. Also, dry snow and ice can be penetrated by several meters below the surface.

Apart from the main TanDEM-X DEM product further DEM products exist and are briefly described in the following section.

4.1 DEM Product Overview

All available TanDEM-X DEM products and their performance goals are shown in Table 1. Further DEM specifications can be found in Section 4.4.1.

TanDEM-X DEM: The TanDEM-X DEM is a global product derived from multiple TanDEM-X DEM acquisitions from December 2010 until January 2015. The northern hemisphere was recorded in ascending geometry, the southern one in descending. Apart from the nominal pixel spacing of 0.4 arcsecond, the TanDEM-X DEM is available with a larger pixel spacing of both 1 arcsecond and 3 arcseconds. The latter have an improved relative vertical accuracy at the expense of detail.

DEMs on special user-request: DEMs on special user-requests with an increased pixel spacing by a factor of 2 were experimentally produced. Operationally, high resolution DEMs (HDEMs) are available for some selected regions. In addition to the finer pixel spacing of 0.2 arcsecond, HDEMs have a better random height error compared to the TanDEM-X DEM. They were realized by completely new coverages with acquisitions from February 2015 to September 2016 with larger baselines and corresponding smaller Height of Ambiguity (HoA) values[1]. HDEMs are available with a scientific DEM proposal (see Section 4.4.4).

TanDEM-X DEM 2020: The TanDEM-X DEM 2020 is a product derived from completely newly acquired DEM acquisitions from the years 2017 to 2022 (mainly from the years 2017 to 2020 plus 2.5% from 2021 to the end of 2022 to close remaining gaps). For the polar regions, data from 2016 and 2017 is added (Greenland timeline: 2016-09-12– 2017-05-19, Antarctica timeline: 2017-04-20 – 2017-09-15). The coverage is mainly realized with a single global coverage. The look direction was opposite to the main look direction of the first TanDEM-X DEM. The northern hemisphere was recorded in descending geometry, the southern one in ascending. Like the TanDEM-X DEM, the TanDEM-X DEM 2020 is available with increased pixel spacings of 1 arcsecond and 3 arcseconds.

[1] The height of ambiguity is defined as the height difference that generates an interferometric phase change of 2π after interferogram flattening (source: InSAR Principles, ESA).

DEM Product	Independent Pixel Spacing	Absolute Horizontal Accuracy, CE90	Absolute Vertical Accuracy, LE90	Relative Vertical Accuracy, 90% linear point-to-point error	Coverage
TanDEM-X DEM					
TanDEM-X DEM **(standard product 0.4 arcsec)**	**0.4 arcsec** **(~12 m @ equator)** see Sec. 4.3.1.3	**<10 m**	**<10 m** **Measured: ~2m ([I20], [I21])**	**2 m (slope ≤ 20%)** **4 m (slope > 20%)**	**global**
TanDEM-X DEM (1 arcsec)	1 arcsec (~30 m @ equator) see Sec. 4.4.2	<10 m	<10 m	Not specified	global
TanDEM-X DEM (3 arcsec)	3 arcsec (~90 m @ equator) see Sec. 4.4.2	<10 m	<10 m	Not specified	global
TanDEM-X DEM 2020					
TanDEM-X DEM 2020 **(standard product 0.4 arcsec)**	**0.4 arcsec** **(~12 m @ equator)** see Sec. 4.3.1.3	**<10 m**	**<10 m** **expected similar to DEM (~ 2m)**	Not specified Expected values: Flat terrain 1 m – 2.5m Forests 2 m – 4.5 m Mountains 2 – 4 m Deserts 2.5 – 7 m Glaciers 2 – 3 m	**global**
TanDEM-X DEM 2020 (1 arcsec)	1 arcsec (~30 m @ equator) see Sec. 4.4.2	<10 m	<10 m	Not specified	global
TanDEM-X DEM 2020 (3 arcsec)	3 arcsec (~90 m @ equator) see Sec. 4.4.2	<10 m	<10 m	Not specified	global
DEMs on special user-request					
HDEM	0.2 arcsec (~6 m @ equator) see Sec. 4.4.4.2	<10 m	<10 m	Goal 0.8 m (90% random height error)	some selected areas

Table 1: TanDEM-X DEM products overview.

4.2 Adopted acquisition plan for the TanDEM-X DEM 2020

During the TanDEM-X DEM 2020 acquisition phase a further global coverage was captured with roughly two acquisitions over mountainous terrain and one acquisition over the rest of the world. The world is furthermore split up into different dedicated areas, as shown in Figure 1. These areas were derived from the experience with TanDEM-X data acquisition and processing. The areas were selected with respect to their vegetation, ice, or terrain type and were acquired with suitable baselines as well as during suitable seasons.

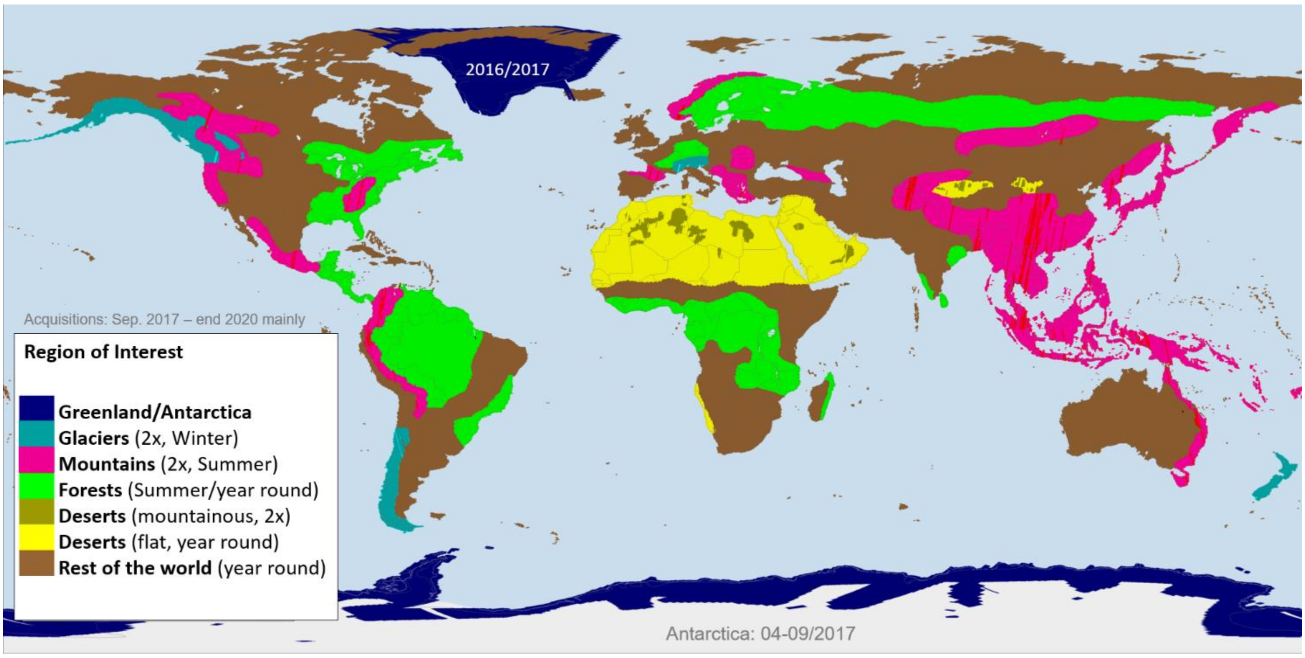

Figure 1: ***Areas covered during the*** **TanDEM-X DEM 2020** ***phase (2017-09-21 – end 2020 mainly): Mountains and mountainous forests (red/pink areas) and glaciers (light-blue) are acquired twice in the suitable season (local winter or summer time). Polar regions (dark blue) are mapped in the respective winter seasons. Mountainous deserts (olive) are acquired twice independent of the season. Temperate and boreal forests (dark and medium green) are acquired once in summertime. Tropical forests (light green) and the rest of the world (brown) are acquired once independent of season.***

4.3 DEM Generation Process

This section provides a brief description of the DEM generation process. It focuses on processing of interferometric bistatic raw data into final mosaicked DEM tiles. Further details can be found in [20].

All operational TanDEM-X DEM acquisitions were processed by two systems: the Integrated TanDEM-X Processor (ITP) and the DEM Mosaicking and Calibration Processor (MCP). The ITP included bistatic focusing and processing of individual scenes into interferograms. These are then phase unwrapped and geocoded. The resulting raw DEMs or DEM scenes have an extent of ~30 km x 50 km [I4]. Within the MCP, these were quality controlled, vertical DEM calibrated and mosaicked into DEM product tiles.

ITP for TanDEM-X DEM: The DEM scene generation process by the ITP differs for the three main mission phases:

- The first global coverage was processed in line with the acquisition progress. The height of ambiguity was adequate to allow a robust phase unwrapping, at least for moderate terrain in a single-baseline approach. However, remaining unwrapping problems for difficult terrain were present in this first coverage data set.
- The second global coverage was shifted by one-half of a swath width. For a robust processing of that data, the first coverage interferograms were used as supporting information within a so-called dual-baseline phase unwrapping procedure [I5], [I6].
- Further coverages from different viewing geometries (e.g. for shadow and layover areas, in high mountain areas, and for other difficult terrain like rain forest or deserts) were processed with either the single- or the dual-baseline algorithm.

- Erroneous scenes from the single-baseline processing were reprocessed using the dual-baseline algorithm before DEM calibration and mosaicking.

The TanDEM-X SAR data was interferometrically processed in a way to enable an independent spacing between two neighboring elevation values. The mosaicked DEM product has a ground resolution of about 10 m to 12 m, therefore, usually 3 x 5 or 5 x 5 original single-look SAR samples of 2.4 m to 4 m were combined for one interferogram pixel.

The ITP used no external reference data for height calibration or phase unwrapping. It relied solely on the excellent synchronization, baseline accuracy, and the delay and phase calibration of the system for DEM geocoding. The reference height for the ambiguous phases was an absolute height derived from the radargrammetric parallactic shift, which was measured directly from the data takes. The remaining offsets and tilts for one data take were in the range of some few meters - for a majority below 2 m. These errors were estimated and compensated for in the follow-on TanDEM-X DEM Mosaicking and Calibration processor (MCP).

ITP for TanDEM-X DEM 2020: For the TanDEM-X DEM 2020 DEM scenes, the so-called Change RawDEMs / CRawDEMs, the phase-unwrapping and interferometric filtering procedure was modified. Since the limited resources and time did not allow for several coverages for the majority of the landmass, it was processed on the basis of the first global TanDEM-X DEM product by a newly developed so-called "delta-phase" approach [I9] in the ITP instead of the Dual-(or Multi-)Baseline-Phase-Unwrapping algorithm developed for the mission. The phase unwrapping was performed on an interferometric phase flattened with edited versions of the first global DEM (the TanDEM-X 30m Edited Digital Elevation Model EDEM for most areas [I23], [I24] and the TanDEM-X PolarDEM in 12m for Antarcica and Greenland [I25], [I26]) to reduce the density and number of the interferometric fringes. It is important to note, that - although the process started with the first global DEM - the new phase (height) values are independent of the old ones due to a sophisticated temporal change dectection and error correction approach. It has been shown in the HDEM generation tests [I8],[I9] that phase unwrapping errors are greatly reduced (nearly eliminated) even for extremely demanding small Height-of-Ambiguity values. Nevertheless, large scale errors in the edited input DEM can not be fully recovered by the process despite the moderate HoAs of the new acquisitions and may hence affect the output DEM performance locally.

The process of delta-phase unwrapping also analyzes temporal changes and uses stable areas for calibration of the absolute height (absolute phase offset) of the CRawDEMs and is thus no longer based on the stereo-radargrammetric data exploitation. Hence, the so-called pi-ambiguities (i.e. wrongly selected height ambiguity bands due to synchronization phase offsets and residual baseline errors) will be avoided. Both facts and the lack of additional coverages facilitate the processing (no more need for re-processing) and calibration process at the cost of less freedom to select suitable CRaw DEM data from the available coverages.

The absolute height accuracy which was driving the use for temporal height change detection is in the same order of magnitude as the first global DEM. Individual remaining offsets for one data take or CRaw DEM are mainly in the sub-meter range. As for the first global DEM, these residual errors are estimated and compensated for in the subsequent TanDEM-X DEM Mosaicking and Calibration processor (MCP).

For DEM calibration ground control points (GCPs) are used:

- The globally available ICESat (Ice, Cloud and Land Elevation Satellite) data are used as absolute ground control [I7], namely the GLA 14 product (Global Land Surface Altimetry Data) from release 31.

- Several selection criteria are considered in order to retrieve reference points from open, non-vegetated and flat terrain only. For those areas, the standard deviation for the selected GCPs is, in most cases, below 2 m [I8], [I9].

Block adjustment (DEM calibration) of generated DEM scenes [I10]:

- Tie points, automatically selected in overlapping areas of neighboring scenes, are used.
- The best ground control points with known absolute heights are chosen for DEM adjustment (ICESat calibration points).
- Each calibration block is set up by an operator selecting all available DEM scenes that passed a previous quality check.
- DEM calibration process: Offsets and tilts are estimated within a least-squares adjustment for each DEM scene or the whole DEM acquisition, respectively.
- The differences between GCPs and DEM as well as differences between tie points before and after the calibration are calculated and displayed. All statistical checks are exclusively based on validation points, i.e. GCPs and tie points, which were not used in the calibration process.
- An operator inspects the results with the help of statistical data and visual plots. Improper or bad quality DEM scenes can be rejected. For the calibration of DEMs over ice caps, i.e. in Greenland and Antarctica, a modified method was applied. Only tie points, and no ICESat calibration points, were used for the inner snow and ice areas. This approach prevents an artificial and massive uplift of the radar scattering plane, which is located in the volume, rather than close to the ice surface [I11]. This leads, especially for Greenland and Antarctica, to height discrepancies to ICESat data of several meters.

Mosaicking into DEM product tiles:

- For Mosaicking a block is set up by an operator selecting all available, calibrated DEM scenes for a region.
- In a first stage of the mosaicking process, the estimated correction parameters of the DEM calibration, regarding the residual offsets and tilts, are applied to each DEM scene.
- Then, all available input scenes for the requested DEM tiles are fused [I12], namely the layer DEM, height error map, amplitude, water indication mask and several other masks.
- For the global TanDEM-X DEM, all available DEM scenes between December 2010 and January 2015 are used as input.
  For the TanDEM-X DEM 2020 all scenes from 2017 (and additionally some from 2016 for Greenland and Antarctica) to end of 2022 are used as input.

Quality analysis (QA) of the mosaicking process:

- A subsequent quality analysis of the mosaicking process is performed on every individual DEM tile by an operator.
- For each tile several quicklooks and statistics are calculated. All results are displayed for QA by a specific inspection tool.
- Based on quicklooks a formal completion check of the product is made.
- Large-size images and KMLs can be opened to check the correctness.
- Especially the quality of the DEM is inspected visually with the help of auxiliary information layers and reference information.
  - Quicklook images of the difference between TanDEM-X DEM and SRTM C-Band are used to inspect larger discrepancies, e.g. for remaining phase unwrapping errors.
  - Quicklook images of the difference images between the single acquisitions are used to inspect irregularities.

- Quality measures to external height reference data are calculated, i.e. mean and standard deviation
    - to reference DEMs (e.g. SRTM, Copernicus DEM GLO-30)
    - to ICESat validation points
    - to kinematic GPS tracks, if available [I21]

  These measures serve as warnings if thresholds are exceeded. Then those tiles are inspected with special attention.
- Special focus is given on inconsistent areas:
    - In case of erroneous input data mosaicking re-runs are foreseen to omit erroneous input DEM acquisitions.
    - In case of remaining errors, these are annotated in the quality remark field, also part of the metadata.

- Finally, to each tile a completeness status (COMPLETED, PRELIMINARY), a quality inspection status (APPROVED, LIMITED_APPROVAL, NOT_APPROVED) and a quality remark is assigned (see also Appendix A.3).
- Relevant quality measures to external height references are annotated in the product metadata (see A.2 list of selected annotation parameters).
- The results are double-checked by a second operator if the assignment with quality parameters is ambiguous.

4.4 TanDEM-X DEM Product Specification

The following specifications are applicable to the global TanDEM-X DEM products.

4.4.1 Accuracy and grid definition

4.4.1.1 Accuracy definitions

The absolute horizontal, absolute vertical and relative vertical accuracies are defined as follows.

- **Absolute horizontal accuracy** is defined as the uncertainty in the horizontal position of a pixel with respect to a reference datum, caused by random[2] and uncorrected systematic[3] errors. The value is expressed as a circular error at 90% confidence level (CE90)[A1].
- **Absolute vertical accuracy** is the uncertainty in the height of a pixel with respect to a reference height caused by random and uncorrected systematic errors. The value is expressed as a linear error at 90% confidence level (LE90) [A1].
- **Relative vertical accuracy** is specified in terms of the uncertainty in height between two points (DEM pixels) caused by random errors. The corresponding values are expressed as linear errors at 90% confidence level (LE90) [A1]. The reference area for two height estimates is a 1° x 1° area, corresponding to approximately 111 km x 111 km at the equator.

4.4.1.2 Coordinate system and grid definition

Horizontal datum:
The horizontal datum used is WGS84 [I13][4] in its newest realization [I14].
Please note that orbit calculations are made in ITRF. ITRF2005 and ITRF2008 (TanDEM-X DEM) are comparable to the WGS realisation WGS84-G1150. ITRF2014 was used for TanDEM-X DEM 2020 comparable to the WGS realisation WGS84-G2139. As the differences between WGS84-G1150/G2139 and its ITRF realizations are negligible (few centimetre range resp. sub-centimetre range) compared to the TanDEM-X horizontal accuracy, they are not taken into account during processing.

Vertical datum:
The vertical datum is per requirement WGS84-G1150 (TanDEM-X DEM) and WGS84-G2139 (TanDEM-X DEM 2020), realized via ITRF. The heights are ellipsoidal heights[4]. The DEM 2020 product has in addition to the ellipsoid height layer a gravity based height layer with respect to the global Earth Gravitational Model (EGM) [I22] 2008 Geoid representing orthometric heights/the mean sea level.

Coordinate System:
All information layers, i.e. gridded data like elevation values are annotated in the geographic coordinate system. Note that the South Pole is represented by several pixels due to the discrete 2-dimensional representation. The North Pole is not part of the TanDEM-X DEM, as there is no land mass present.

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[2] random errors are high-frequency errors with low spatial correlation contributing to both the point-to-point relative vertical accuracy and the absolute vertical accuracy.
[3] systematic errors denotes uncorrected large scale errors with low spatial frequencies.
[4] WGS84 ellipsoid parameters: semi-major axis a = 6378137.0m, semi-minor axis b = 6356752.3142m

Grid definition:
The coordinates of the center of the corner pixels of a DEM tile always refer to integer values in latitude and longitude (see Figure 2). Therefore, there is a 1-pixel overlap to neighboring tiles, i.e. every first/last pixel row/column will be part of adjacent tiles as well.
The DEM file naming convention refers to the center of the southwest pixel. Note that the center coordinate of the upper left pixel is annotated in the GeoTIFF output file. This corresponds to the 'RasterPixelIsPoint' raster space definition (value of tag GTRasterTypeGeoKey is set to '2') [I15].

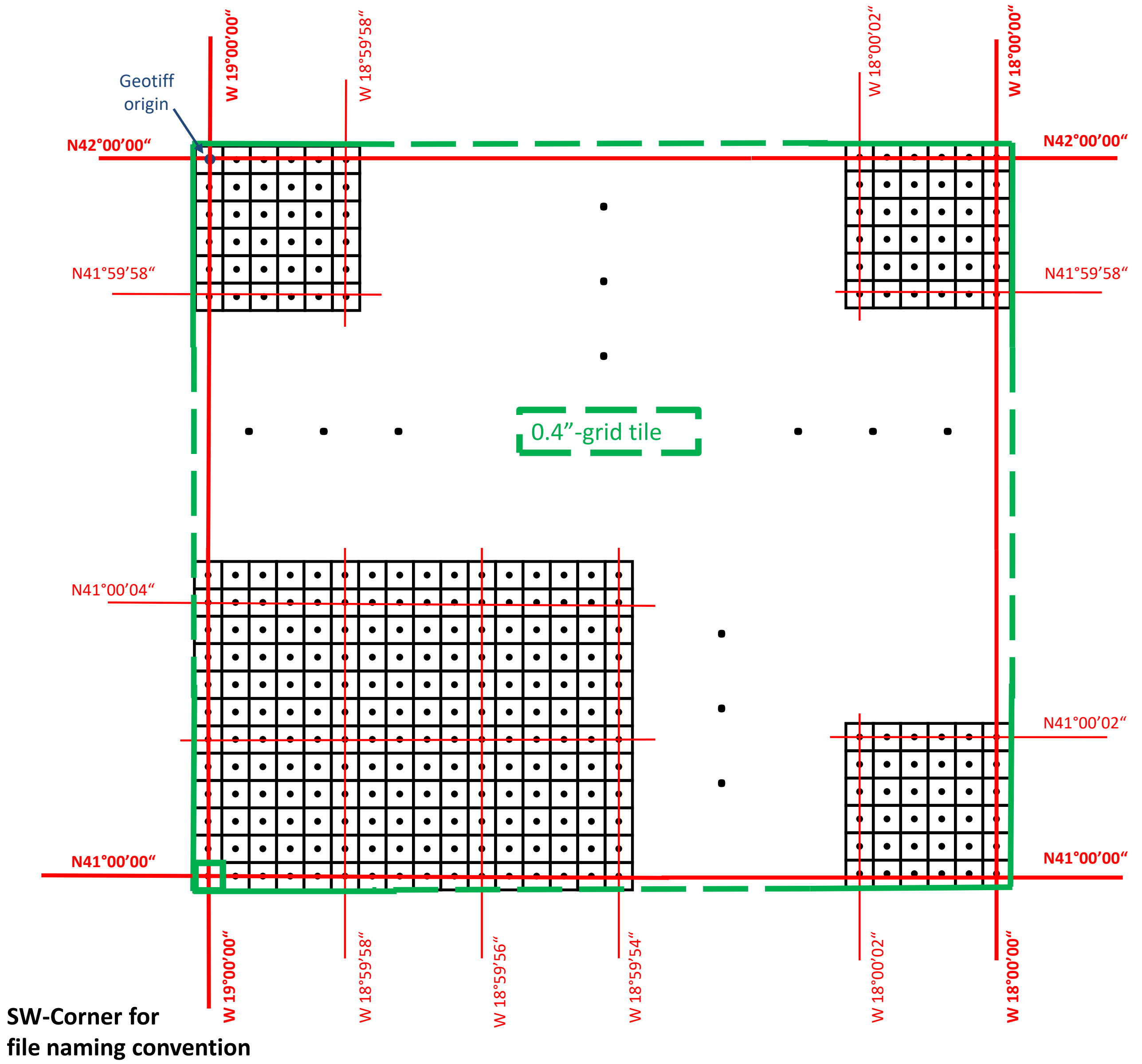

Figure 2: Grid definition for DEM tiles. The coordinates of the latitudes and longitudes of the center of the corner pixels (e.g. W19°00'00'', N41°00'00'') are always integer values. The file naming convention refers to the southwest corner (SW), here N41W019. Please note that in contrast to this file naming convention the annotated ModelTiepointTag in the GeoTIFF header refers to the pixel center in the northwest corner.

4.4.1.3 TanDEM-X DEM pixel spacing

The pixel spacing for the standard product in latitude direction is 0.4 arcseconds, which corresponds to 12.37 meters at the equator and to 12.33 meters near the poles. The longitudinal pixel spacing varies depending on latitude between 0.4 arcseconds at the equator and 4 arcseconds above 85° N/S latitude, as shown in Table 2. The subdivision into six different longitude posting zones is made in a way to obtain roughly quadratic ground sampling distances.

Zone	*Latitude*	*Latitude pixel spacing*	*Longitude pixel spacing*
I	0° – 50° North/South	0.4’’	0.4’’ (12.37m – 7.95m)
II	50° – 60° North/South	0.4’’	0.6’’ (11.92m – 9.28m)
III	60° – 70° North/South	0.4’’	0.8’’ (12.37m – 8.46m)
IV	70° – 80° North/South	0.4’’	1.2’’ (12.69m – 6.44m)
V	80° – 85° North/South	0.4’’	2.0’’ (10.74m - 5.39m)
VI	85° – 90° North/South	0.4’’	4.0’’ (< 10.78m)

Table 2: Pixel spacing for TanDEM-X DEM depending on latitude.

4.4.2 Information Layers

The DEM production comprises the generation of the following information layers:

Component name	*Description*
DEM	elevation data in ellipsoidal height
MSL	elevation data in orthometric/mean sea level height (DEM2020 only)
HEM	height error map
AMP	SAR amplitude mosaic (mean value)
AM2	SAR amplitude mosaic (minimum value)
WAM	water indication mask
COV	coverage map
COM	consistency mask
LSM	layover & shadow mask

Table 3: TanDEM-X DEM product components.

The processing step of interpolating small spots of outlier pixels was discarded for the final DEM generation, since the number and magnitude of outliers is very low in the DEM product. All DEM information layers are described in more detail in the following sections.

4.4.2.1 Digital elevation model (DEM)

The elevation values represent the ellipsoidal heights relative to the WGS84 ellipsoid in the WGS84-G1150 datum. One elevation value h reflects a weighted height average for a given pixel, computed by the height values of all contributing DEM scenes (Eq. 1).

$$h = \frac{\sum_{k=1}^{K} w_k h_k}{\sum_{k=1}^{K} w_k} \quad \text{(Eq. 1)}$$

The weights w_k are inversely proportional to the corresponding standard deviations σ_{HEM} of the height error map (HEM). Note the higher height errors σ_{HEM} the smaller the impact on the final height value. The height errors are additionally increased towards the scene borders in order to ensure a seamless DEM mosaic.

Values:	ellipsoidal heights
Units for elevation values:	meters
Invalid values for unknown or missing data:	-32767.0 (similar to SRTM convention)

Invalid values will be set in case of:

- no DEM data is available
- very incoherent areas with respect to certain predefined thresholds (e.g. over deserts, open water, forest)

A reduced reliability of a pixel (such as heights from single coverages, or values with height inconsistencies between several acquisitions) can be rated with the help of the following layers, in particular with the height error map, the height consistency mask and the coverage map.

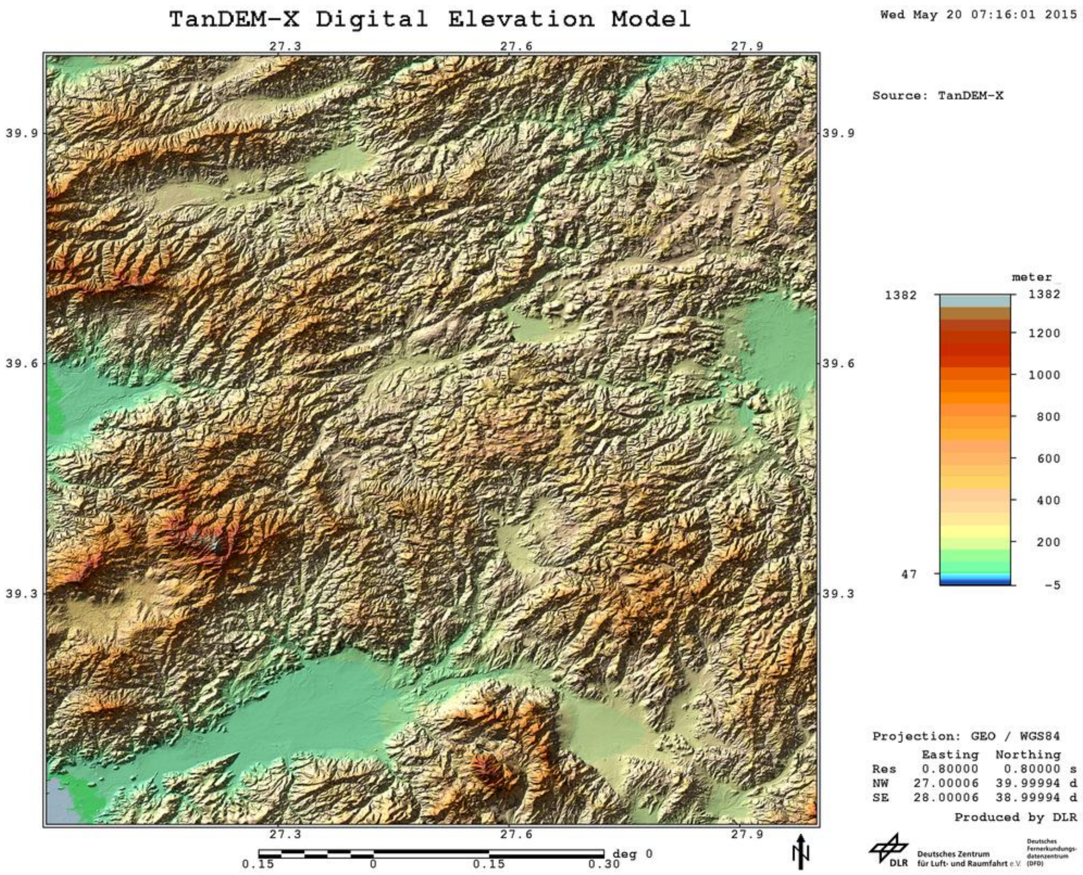

Figure 3: Quicklook "mountains": DEM tile, color-coded, with shaded relief, and with legend.

4.4.2.2 Digital elevation model in orthometric/mean sea level heights (MSL)

The elevation values of the mean sea level (MSL) Layer represent orthometric heights. The orthometric height is defined as the vertical distance from a point on the surface to the geoid. Whereas, the Geoid height respectively geoid undulation (N) is the vertical distance between the reference geoid and the ellipsoid.The geoid is the hypothetical shape of the Earth's surface, which often coincides with the mean sea level (MSL) and its imagined extension above or below land areas. One realization of the equipotential surface of the MSL is the global Earth Gravitational Model (EGM2008) [I22].

MSL or orthometric heights are derived from the DEM in ellipsoidal heights (H_{ell}) by substracting the geoid, also called geoid undulation, here EGM2008 geoid undulations $N_{EGM2008}$. (See Fig. 4 and [I22])

$$H_{MSL} = H_{ell} - N_{EGM2008} \quad \text{(Eq. 2)}$$

Values:	orthometric heights
Units for elevation values:	meters
Invalid values for unknown or missing data:	-32767.0

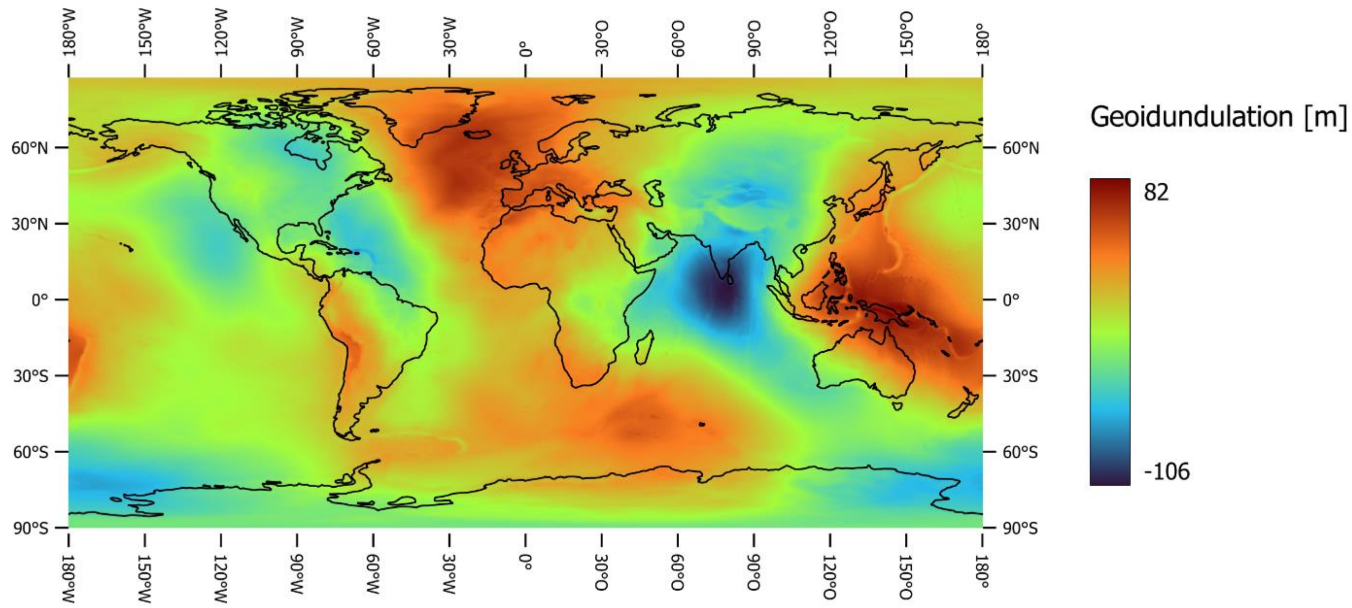

Figure 4: Geoid undulation from EGM2008. These values are substracted from to the ellipsoidal DEM to obtain orthometric elevation values for MSL DEM layer.

4.4.2.3 Height error map (HEM)

The height error map values represent for each DEM pixel the corresponding height error in form of the standard deviation. The value is derived from the interferometric coherence and from geometrical considerations [I16] and represents the result of a rigorous error propagation. This height error is considered to be a random error. Thus, it does not include any contributions of systematic errors, e.g. elevation offsets related to erroneous orbital parameters, or other error types. Above all, unwrapping errors are not represented. The interferometric coherence is estimated from an extended window of the size of usually 11 x 11 complex samples, hence the error values annotated in the HEM of the 0.4" resolution DEM are locally correlated by 2-3 pixel, while the DEM values are uncorrelated.

The mosaicked height error values are derived by error propagation from the equation for the height values using the same weights w_k as in (Eq. 1):

$$\sigma_{HEM} = \sqrt{\frac{\sum_{k=1}^{K} {w_k}^2 \sigma_{HEM,k}^2}{(\sum_{k=1}^{K} w_k)^2}} \qquad \text{(Eq. 3)}$$

with $\sigma_{HEM,k}$ as height error value estimated from coherence and geometrical considerations for each DEM scene.

Values:	standard deviations
Units for height error values:	meters
Invalid values for unknown or missing data:	-32767.0

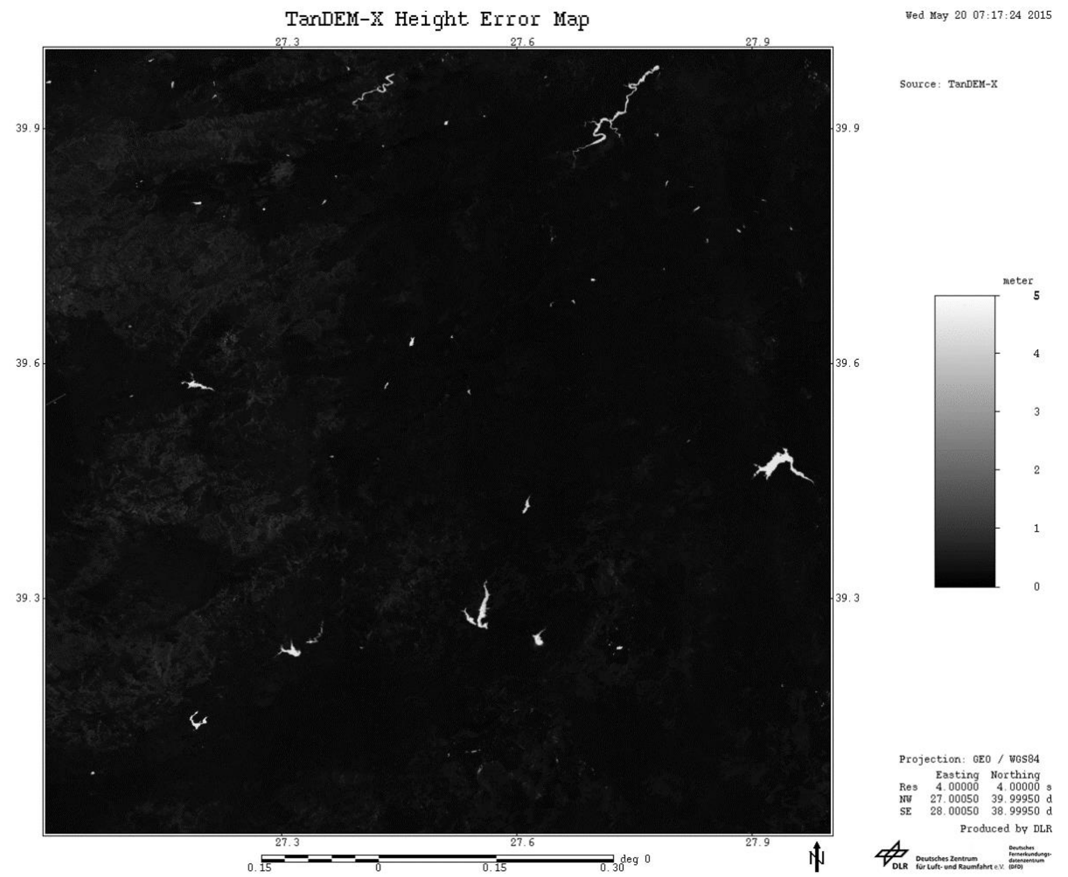

Figure 5: Quicklook "mountains": HEM. Valid HEM values are scaled from 16bit to 8bit, and represent a range between 0 – 5 m.

4.4.2.4 Amplitude mosaic (AMP) – representing the mean value

The amplitude mosaic is a by-product generated for further processings, e.g. water body detection or DEM filtering). It is a mosaic calculated by the mean of all calibrated amplitude values from the contributing DEM scenes (in general between 2 and up to 10 scenes). The amplitudes are comprising of the master channel of the InSAR scenes. Equation (4) was used to calculate the calibrated amplitude values $DN_{CAL,i}$ for each single contributing scene *i*.

$$DN_{CAL,i} = DN_i \sqrt{\frac{CAL\_fac\_i * \sin(\theta_i)}{CAL\_fac\_const * \sin(45°)}} \qquad \text{(Eq. 4)}$$

where:
θ_i: incidence angle at scene center of each input scene
CAL_fac_const: $1*10^{-5}$ calibration constant
CAL_fac_i: individual calibration factor per input scene
DN_i : digital number per input scene

The annotated digital numbers DN_{CAL} consist of an average of all contributing $DN_{CAL,i}$

$$DN_{CAL} = 1/I \sum_{i=1}^{I} DN_{CAL,i} \qquad \text{(Eq. 5)}$$

Sigma nought values for a single pixel of the mosaic can be approximated from the annotated DN_{CAL} values by applying:

$$\sigma_0 = DN_{CAL}^2 CAL\_fac\_const * \sin(45°) \cdot \qquad \text{(Eq. 6)}$$

Values:	amplitude values
Units for amplitude values:	none, calibrated digital numbers (DN_{CAL})
Invalid values for unknown or missing data:	0

4.4.2.5 **Amplitude mosaic (AM2) - representing the minimum value**

The amplitude mosaic is a by-product generated for further processings, e.g. water body detection or DEM filtering. It is a mosaic containing the minimum value of all calibrated amplitude values from the contributing DEM scenes (in general between 2 and up to 10 scenes). The amplitudes are comprising of the master channel of all contributing InSAR scenes. The digital amplitude values can be transformed into radar backscatter sigma nought according to Equation (6).

Values:	amplitude values
Units for amplitude values:	none, calibrated digital numbers (DN_{CAL})
Invalid values for unknown or missing data:	0

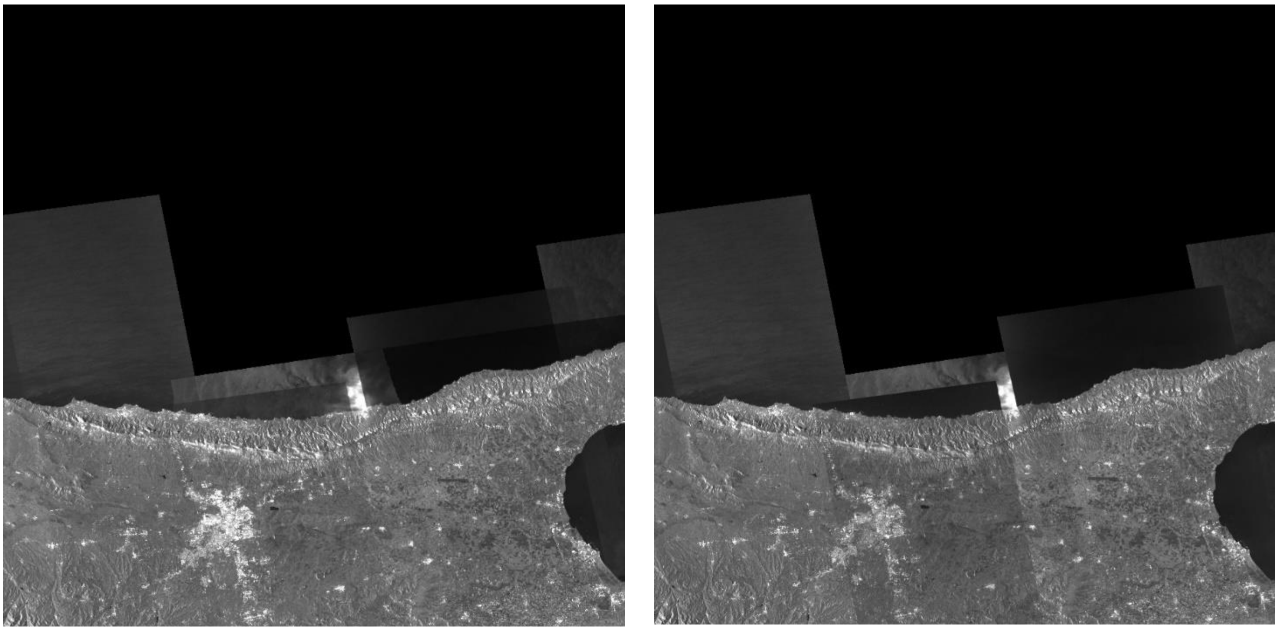

Figure 6: Quicklook "coast": AMP and AM2.

4.4.2.6 Water indication mask (WAM)

Water bodies identified during processing will be flagged in the water indication mask. Islands with an area smaller than 1 hectare (100 x 100 m²) and water bodies with an area below 2 hectares (200 x 100 m²) will not be included in the water indication mask. Please note that water body heights are not edited in the DEM. Water bodies are generally very incoherent areas in the underlying DEM scenes and thus derived height estimates are very noisy, and might not contain any meaningful height value at all.

The water body detection for the WAM layer is a fully automated process. To reduce the amount of misclassifications, three external references (a global landcover classification derived from MODIS, the SRTM water body mask, and the SRTM DEM) are used in a first step for the initialization of the finally derived water mask. The following areas are not further considered by the TanDEM-X water indication algorithm:

1. Areas where both the MODIS landcover classification and the SRTM water body data (SWBD) indicate dry regions respectively no water. In the MODIS landcover data set [I17], these areas are given by the classes: "snow and ice" and "unvegetated/barren and sparsely vegetated", depicted in white respectively yellow in Figure 7. The minimum spatial extent of these two land cover classes was used within the period 2001 – 2004.

2. The SRTM DEM is used to identify steep slopes in order to prevent the misinterpretation of radar shadow as water. All areas with a slope above 20° are excluded from the water body detection. Outside SRTM no exlusion of slopes is performed.

3. Additionally, all areas already identified as shadow and layover based on the SRTM and GLOBE DEM during the TanDEM-X DEM processing are also excluded.

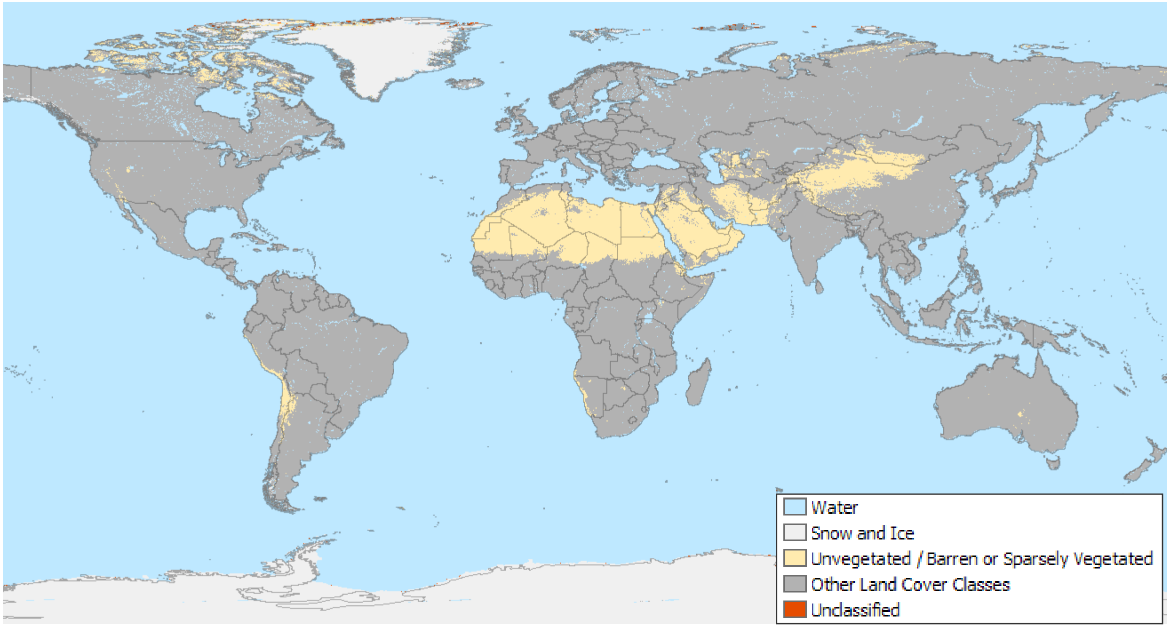

Figure 7: World map showing "snow and ice" and "unvegetated" land cover classes based on "MODIS / Terra Land Cover Types MOD12C1" [I17].

Bit value								*Meaning*
2^0	2^1	2^2	2^3	2^4	2^5	2^6	2^7	
0	0	0	0	0	0	0	0	0: Invalid
1								1: valid DEM value
1	**1**	**0**						1x water detected with *relaxed* AMP-Thresh2
1	**0**	**1**						2x water detected with *relaxed* AMP-Thresh2
1	**1**	**1**						3x or more times water detected with *relaxed* AMP-Thresh2
1			**1**	**0**				1x water detected with *strict* AMP-Thresh1
1			**0**	**1**				2x water detected with *strict* AMP-Thresh1
1			**1**	**1**				3x or more times water detected with *strict* AMP-Thresh1
1					**1**	**0**		1x water detected with COH-Thresh
1					**0**	**1**		2x water detected with COH-Thresh
1					**1**	**1**		3x or more times water detected with COH-Thresh
1							**1**	water body detection is not performed according to MODIS classes or SRTM

Table 4: Water indication flags: Bit counter for water detection: amplitude threshold 1 (strict threshold), amplitude threshold 2 (relaxed threshold), and coherence threshold; empty bits in the Table can be zero or one.

The water indication mask contains flags indicating the count of detected water per pixel found by three different detection methods:

1. strict beta nought threshold for the SAR amplitude (***strict AMP Thresh1***, of -18 dB)
2. more relaxed beta nought threshold for the SAR amplitude (***relaxed AMP Thresh2***, of -15 dB)
3. threshold for the interferometric coherence (***COH Thresh***, of < 0.23).

The values in the WAM are coded in a bit mask, see Table 4. Each bit value reflects the number of acquisitions with detected water which fulfill at least one of the above mentioned conditions. The maximum number of annotated counts is 3.

Values:	flags/number of occurrences
Units for water values:	coded bit values
Invalid values for unknown or missing data:	0

For deriving a binary water mask it is possible to threshold the 0 – 255 WAM byte values, i.e. by selecting values from 3 to 127, a maximum extent water mask will be retrieved. By selecting values from 33 to 127, a WAM just based on the coherence can be obtained.

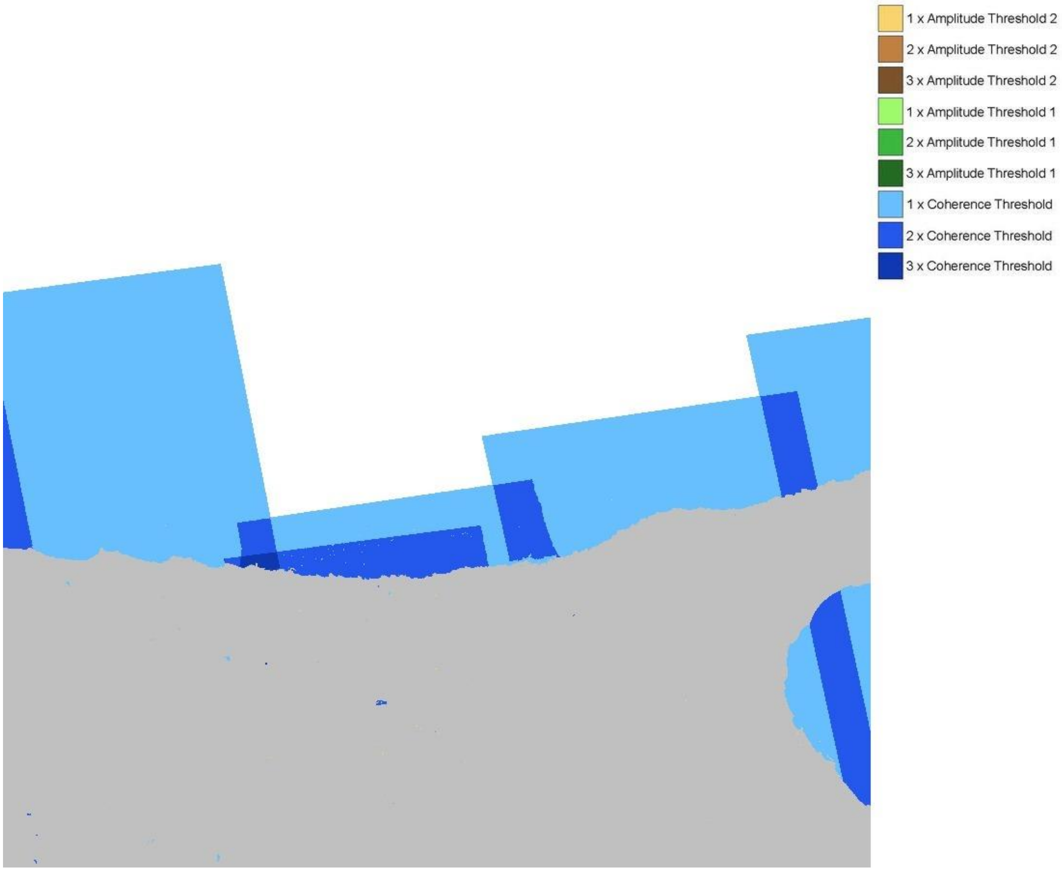

Figure 8: Quicklook "coast": water indication mask with legend, the colors indicate the water detections. Note that if both, coherence and amplitude methods detect water, the coherence counter will be displayed.

4.4.2.7 **Coverage map (COV)**

The coverage map indicates how many *valid* height values from different DEM acquisitions were available for mosaicking. Even pixels which do not significantly contribute to the final height value are included in the coverage map.

Values:	number of contributing coverages
Units for coverage values:	none, integer
Invalid values for unknown or missing data:	0

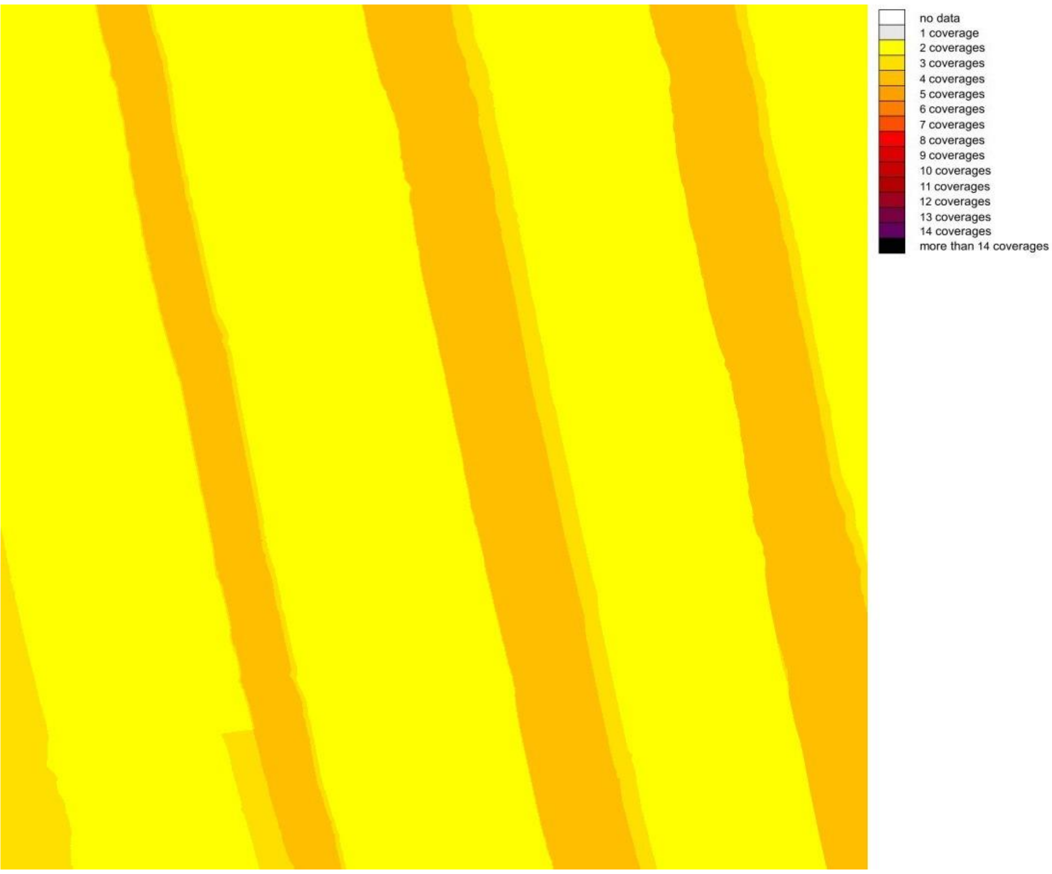

Figure 9: Quicklook "mountains": coverage map with legend.

4.4.2.8 **Consistency mask (COM)**

The consistency mask indicates DEM pixels, which have height inconsistencies among the contributing DEM scenes (Table 5). Two types of height inconsistencies can be distinguished:

- Large absolute height differences (e.g. due to phase unwrapping errors, or due to incoherent areas like water bodies, shadows, layovers)
- Small absolute height differences exceeding the corresponding height errors (e.g. due to temporal changes).

Values:	flags
Units for inconsistent values:	none, bit values

Invalid values for unknown or missing data: 0**Bit value**				**Byte value**	**Meaning**
2^0	**2^1**	**2^2**	**2^3**		
0	0	0	0	0	Invalid/no data
1	0	0	0	1	Larger inconsistency
0	**1**	0	0	2	Smaller inconsistency
0	0	**1**	0	4	Only one coverage
0	*0*	*0*	***1***	*8*	All heights are consistent
1	*0*	*0*	***1***	9	Larger inconsistency but at least one consistent height pair
0	***1***	*0*	***1***	10	Smaller inconsistency but at least one consistent height pair

Table 5: Meaning of bits and bytes in the consistency flag mask, for byte values larger than 8 at least one consistent height pair is present.

Figure 10 shows the workflow of detecting height inconsistencies. Between all input heights the height differences are computed for each pixel. If all height differences are smaller than a given threshold (which depends on the height of ambiguity (HoA)) and their error bars overlap, all input height values are consistent and therefore used for mosaicking (byte value COM=8).

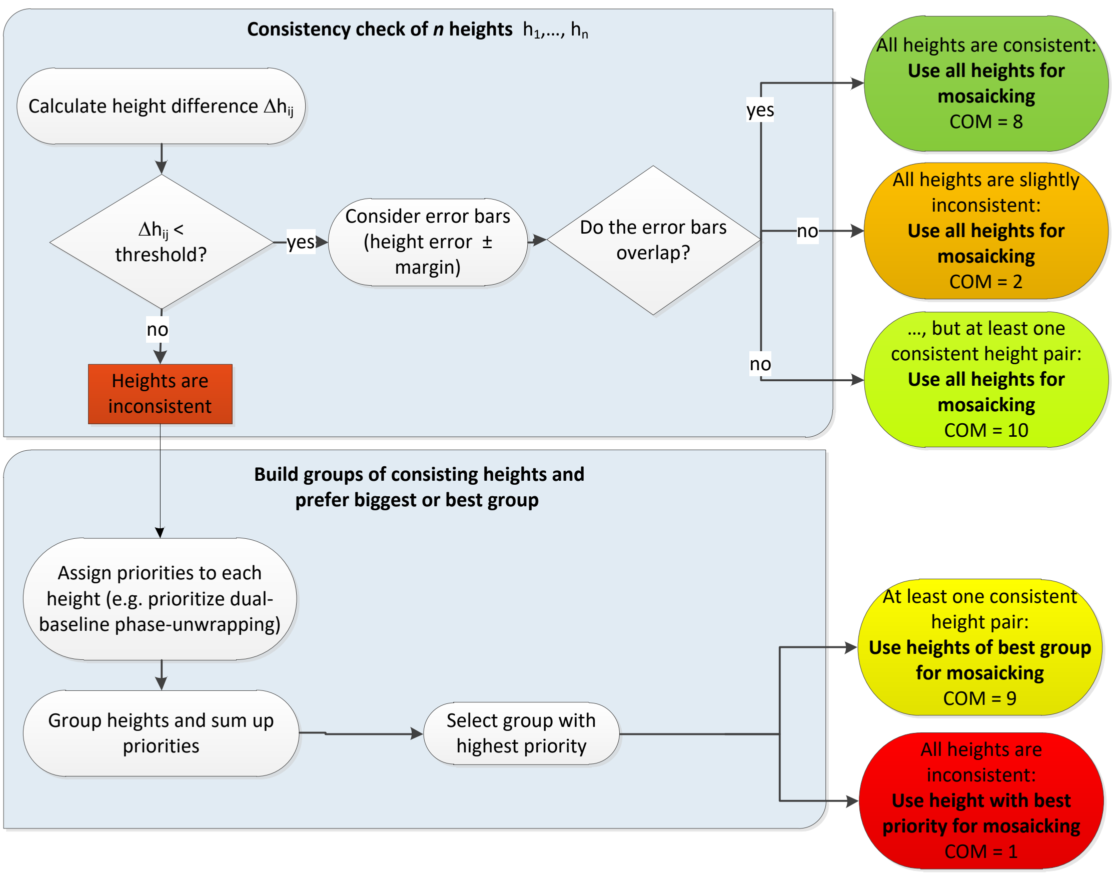

Figure 10: Mosaicking rules and COM values for pixels with more than one input height value.

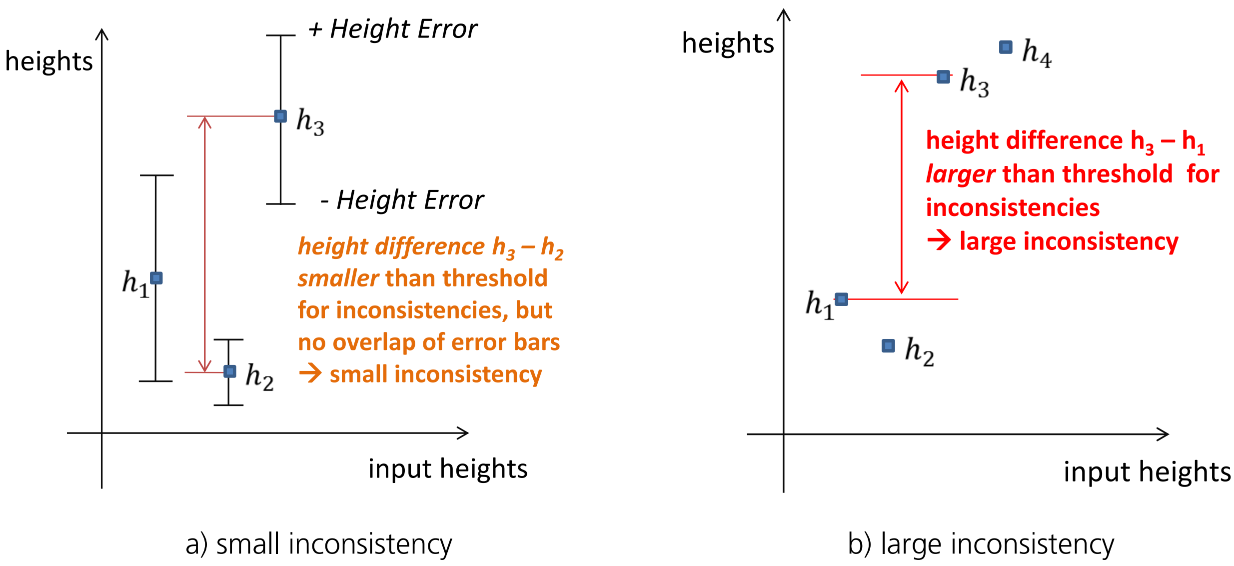

Figure 11: Detection of a) small inconsistency between h_3 and h_2 because their error bars do not overlap and b) large inconsistency between height groups (h_1,h_2) and (h_3,h_4).

Small inconsistency (byte value COM = 2, or COM = 10): If all input heights for a pixel are within the given threshold for inconsistencies but the error bars of one height pair do not overlap (see Figure 11a), a small inconsistency is annotated in the COM. Small inconsistencies correspond to bit value 2^1=> value 2 in Table 5. But if in addition at least one consistent height pair is found for this pixel, the bit value 2^3 will be set (value 8). Thus, yielding a COM value of 2 + 8 = 10 for a pixel with at least one consistent height pair and one or more height values with small inconsistencies.

Large inconsistency (byte value COM = 1, COM = 9): If one height difference of all input heights for one pixel is greater than a certain threshold (compare lower block of Figure 10 and Figure 11b), a large inconsistency is indicated in the COM (bit value 2^0 => value 1 in Table 5). In this case, only heights belonging to one height level shall be chosen for averaging. Having more than two input heights, groups of consistent heights are built. For each height a priority value is assigned according to several quality indicators [I12], e.g.:

- DEM scenes after dual-baseline phase unwrapping typically have less phase unwrapping offsets than DEMs processed with single-baseline phase unwrapping, and thus, are assumed to be more reliable except the height error exeeds a certain threshold
- Processing quality flags are considered
- Acquisitions with large height of ambiguities are considered to be more robust in the phase unwrapping process

Note that apart of the annotated inconsistencies in the COM, there might be remaining height discrepancies due to real height changes (seasonal/temporal) or phase unwrapping errors that are not annotated.

The priority values for each group are summed up. The heights of the group with the highest priority value are used for the DEM mosaicking. The other heights will not impact the mosaicked height value.

If during the whole process for a single pixel a large inconsistency is detected, then all small inconsistency flags are discarded.

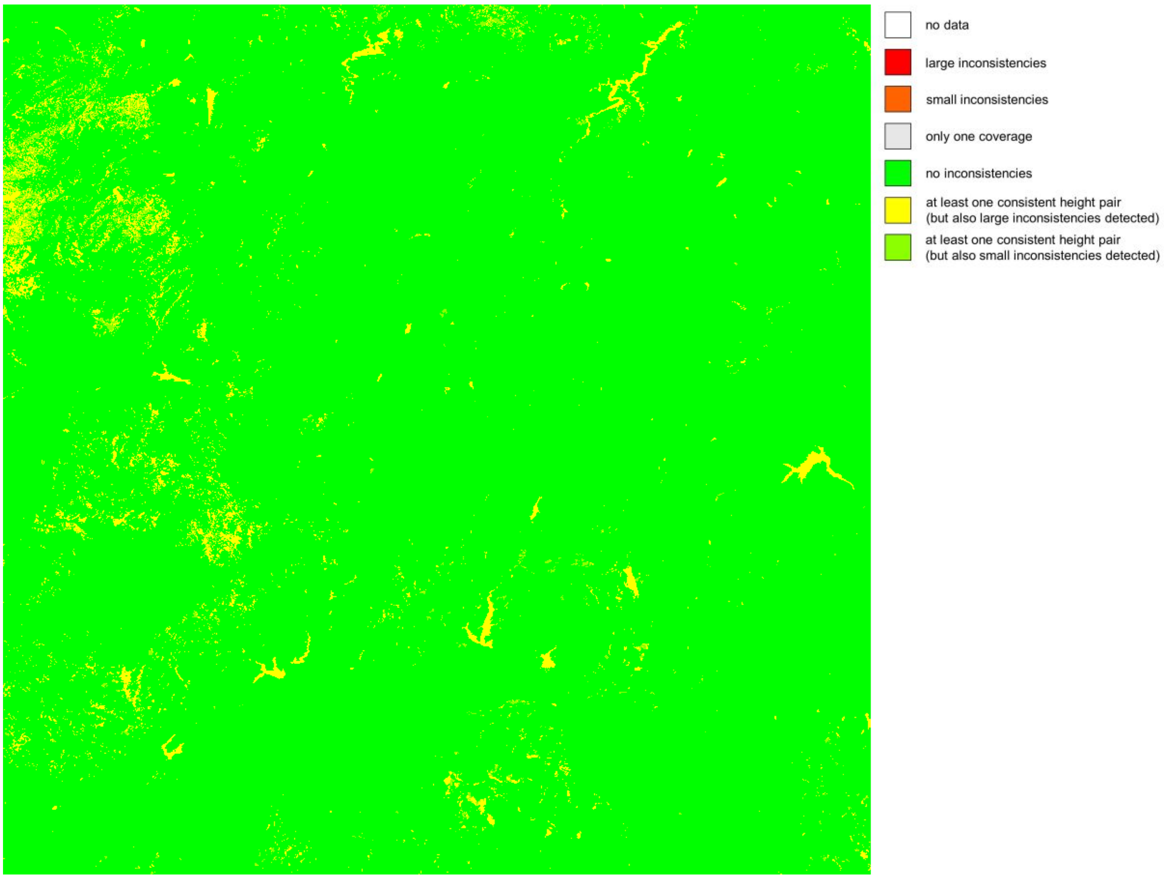

Figure 12: Quicklook "mountains": consistency mask with legend. Note that some of the yellow inconsistent height values are caused by water bodies, some by mountains.

4.4.2.9 Layover and shadow mask (LSM)

For TanDEM-X DEM, the layover and shadow mask (LSM) is based on the SRTM-C DEM and the GLOBE DEM regarding the TanDEM-X geometry of each individual scene. It serves only as a rough estimate for many regions. For TanDEM-X DEM 2020, the LSM is based on the TanDEM-X 30m Edited Digital Elevation Model EDEM for most areas [I23], [I24] and the TanDEM-X PolarDEM in 12m for Antarcica and Greenland [I25], [I26]. The LSM numbers are coded as bit values, see Table 6. A layover or shadow flag is only present when *all* mosaicked DEM acquisitions contain layover/shadow for the respective DEM pixel.
The LSM is not used as input for mosaicking of different individual DEM acquisitions, i.e. potential layover and shadow values are mosaicked according to their HEM values.

Values:	flags
Units for layover and shadow values:	coded bit values
Invalid values for unknown or missing data:	0

Bit value			*Meaning*
2^0	2^1	2^2	
0	0	0	Invalid/no data
1			Valid DEM value
1	**1**		Shadow
1		**1**	Layover
1	**1**	**1**	Shadow + Layover

Table 6: Meaning of bits in the layover and shadow mask, empty bits can be zero or one.

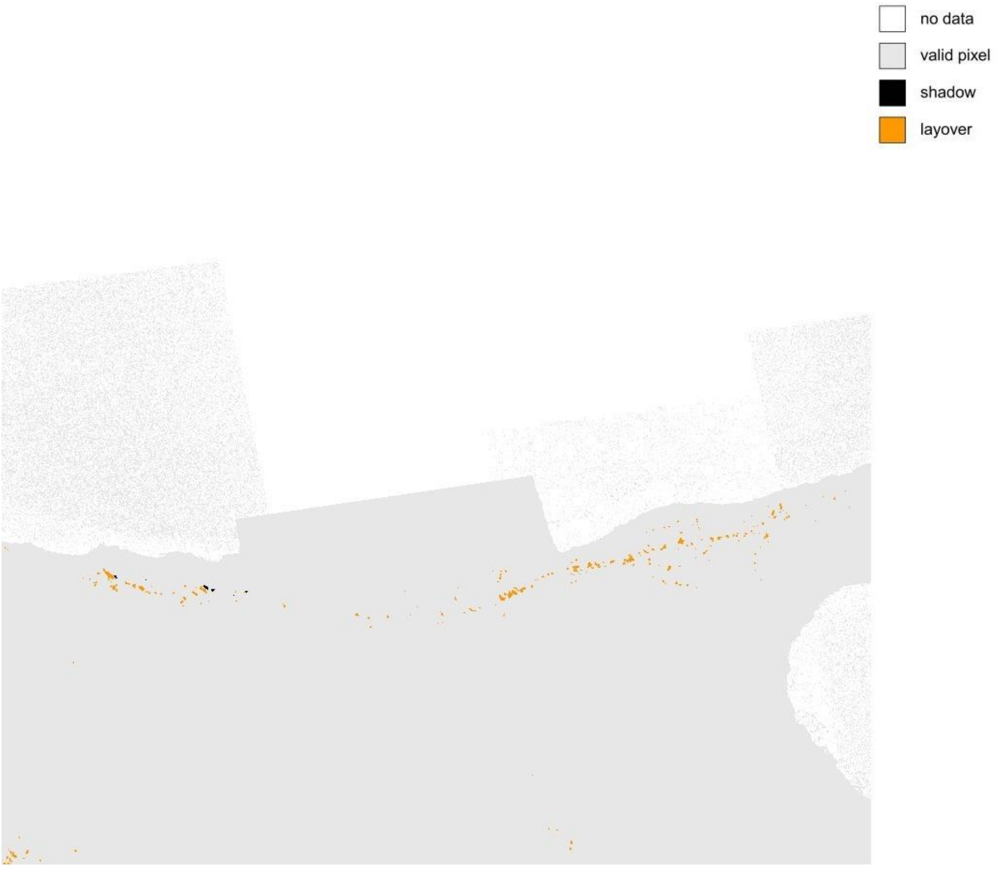

Figure 13: Quicklook “coast”: Layover and shadow mask.

4.4.3 Structure of DEM Product

4.4.3.1 File naming convention

The file naming convention is standardized as follows:

TDM1_tttt_nn_BbbXxxx_FFF.tif

(e.g. TDM1_DEM__04_ N64W018_HEM.tif, TDM1_DEM__10_ S25E138_DEM.tif)

The underscores are literals, i.e. remain unchanged for all files. The other letters have the following meanings:

Letter	Meaning	Example
tttt	product type, i.e. DEM_, HDEM, DEM2 (=DEM2020)	DEM_
nn	Spacing, 04: original spacing, 10: reduced to 1-arcsecond grid, 30: reduced to 3-arcsecond grid	04
B	"N" if the southwest corner of the tile is on the equator or north of it. "S" if it is south of the equator.	N
bb	2-digit latitude value of the southwest corner of a tile in degrees.	64
X	"E" if the southwest corner of the tile is in the eastern hemisphere, "W" otherwise. If the center of the southwest pixel of the tile is exactly at 0° longitude, this is "E". If the center of the southwest pixel is exactly at ±180° longitude, this is "W".	W
xxx	3-digit longitude value of the southwest corner of a tile in degrees.	018
FFF	File type, will be one of the following: DEM (for the elevation data) MSL (for orthometric/mean sea level elevation data) (just for DEM2020) HEM (for the height error map) AMP (for the mean amplitude mosaic) AM2 (for the minimum amplitude mosaic) WAM (for the water indication mask) COV (for coverage map) COM (for the consistency mask) LSM (for the layover and shadow mask)	HEM

Table 7: File naming convention.

4.4.3.2 Product files and product structure

The DEM tiles are delivered to the user in a compressed format (*.tar.gz file extension). After unzipping and de-taring of the compressed file the product folder structure should look as described in the following paragraph and as depicted in Figure 14.

- **Delivery folder:** Naming convention: **dims_op_oc_dfd2_<Packet-ID>_<VolumeID>**
  - **tools:** contains product-specific supplements like product information as well as the latest XSDs
  - **readme.html:** is a file containing the delivery volume with links to individual products
    - **TDM.DEM.<product type>:** folder for DEM product, with DEM type specific naming, i.e. <product type> stands for 'IDEM' or 'DEM'
      - **TDM DEM Product:** Naming convention for a DEM product folder according to the file naming convention plus Version Vvv and geocell coverage G: "C" for Completed and "P" for Preliminary: **TDM1_tttt_nn_BbbXxxx_Vvv_G** (see also Section 4.4.3.1). The TDM DEM Product directory contains the following subdirectories/files:
        - **DEM:** containing the elevation data stored in the DEM and MSL file.
        - **AUXFILES:** containing auxillary DEM information layers (see Section 4.4.2) following the file naming convention TDM1_tttt_nn_BbbXxxx_FFF.tif (see Section 4.4.3.1)
        - **PREVIEW:** containing quicklooks for the DEM as well as for all auxillary information layers following the file naming convention in Section 4.4.3.1 with the extension "_QL": TDM1_tttt_nn_BbbXxxx_FFF_QL.tif. Additionally, it contains a bundle of KML files: one with outlines of all contributing scenes, and one for each information layer with its corresponding quicklook.
        - metadata file in XML format following the file naming convention TDM1_tttt_nn_BbbXxxx.xml and XSDs for formatting the metadata.

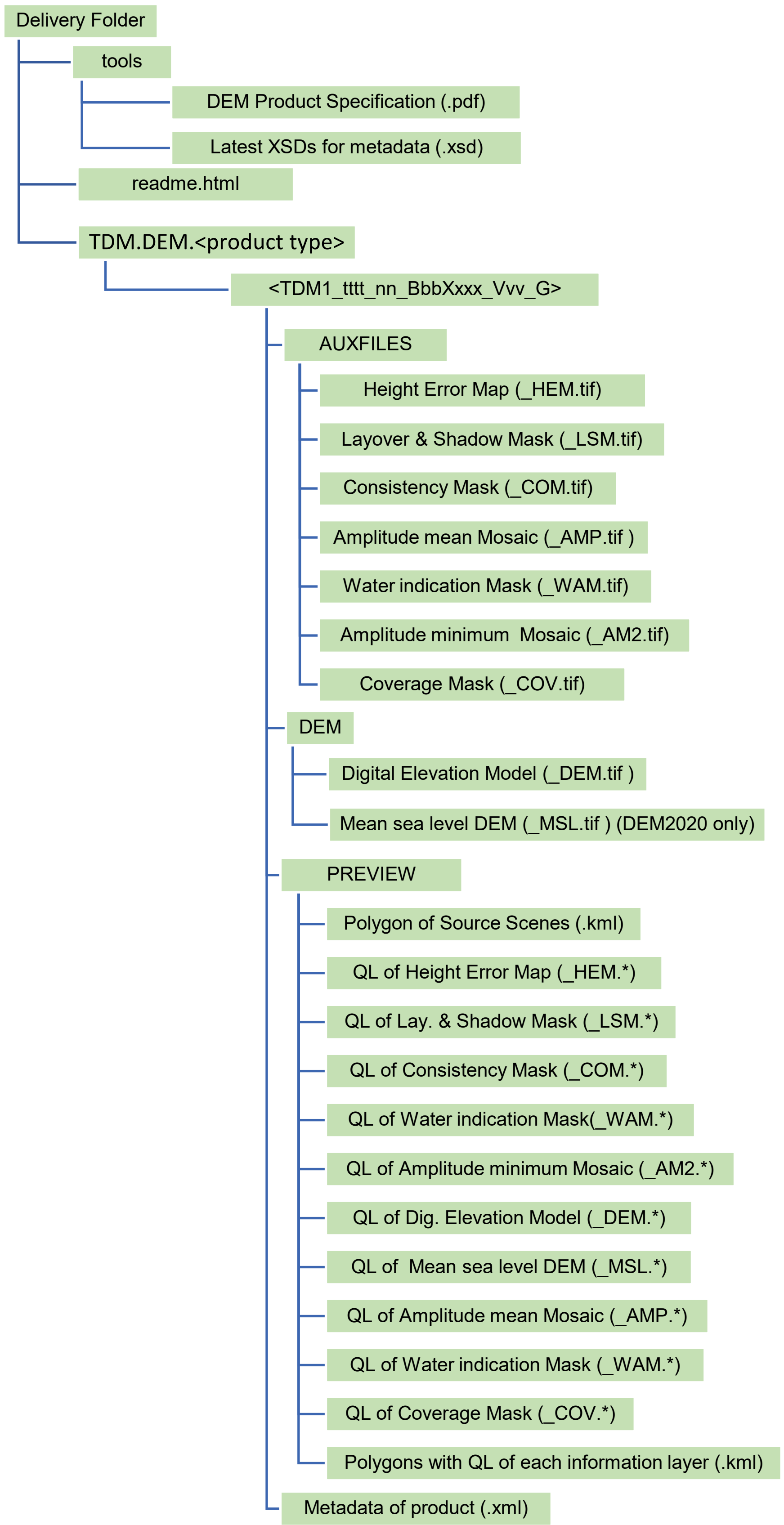

Figure 14: Directory structure of DEM product, * stands for PNG or GeoTIFF.

4.4.3.3 **PREVIEW product files**

Quicklook images without a legend and map border will be delivered in GeoTIFF format. The GeoTIFF quicklooks have an associated KML file, which can be utilized to display the quicklooks in Google Earth as an image overlay. Quicklooks with a legend will be delivered in PNG format and do not have an accompanying KML.

Please note that the polygons given by the quicklook GeoTIFF header and the KML do not exactly match with the outer boundary given by the main DEM GeoTIFF or the information layer GeoTIFFs.

For each DEM tile there is also a KML file ('TDM1_tttt_nn_BbbXxxx.kml') available containing the outline of the DEM tile as well as the outlines of all contributing RawDEMs. Basic scene information parameters (acquisition ID, scene number, acquisition date) are provided as well within this KML.

4.4.3.4 **METADATA product files**

The metadata will be delivered in "XML" format.

The XML file is following the file naming convention 'TDM1_tttt_nn_BbbXxxx.xml'.

In the XML schema (.xsd file) all parameters with a short description are listed.

In the Appendix A.2 a table lists the most important parameters with their description. Also, an overview of the structure of the XML is given.

4.4.3.5 **Raster file formats, bit depth, and data type**

The file format for all information layers is TIFF, a GeoTIFF header is provided according to [I15], and the byte order is always big-endian. However, the bit depth and data type for the image layers is different and given by Table 8.

Information layer	*Bit depth*	*Number of bytes*	*Data type*
AMP	16	2	unsigned integer
AM2	16	2	unsigned integer
COM	8	1	unsigned integer
COV	8	1	unsigned integer
DEM	32	4	float single precision
HEM	32	4	float single precision
LSM	8	1	unsigned integer
MSL (DEM2020 only)	32	4	float single precision
WAM	8	1	unsigned integer

Table 8: Information layer bit depth, number of bytes, and data type.

The quicklook raster file format is either TIFF with a GeoTIFF header according to [I15], or PNG. PNG files and colored GeoTIFF quicklooks for HEM and DEM are in 24bit, others in 8bit.

4.4.3.6 Product tile extent

All products are distributed in 1° x 1° tiles between 0° - 60° North/South latitudes. Between 60° - 80° North/South latitudes one product tile has an extent of 1° x 2°, between 80° - 90° North/South latitudes one product tile has an extent of 1° x 4°, see Figure 15. The product size with all the informations layers and without meta data annotation or quicklooks are listed in Table 9.

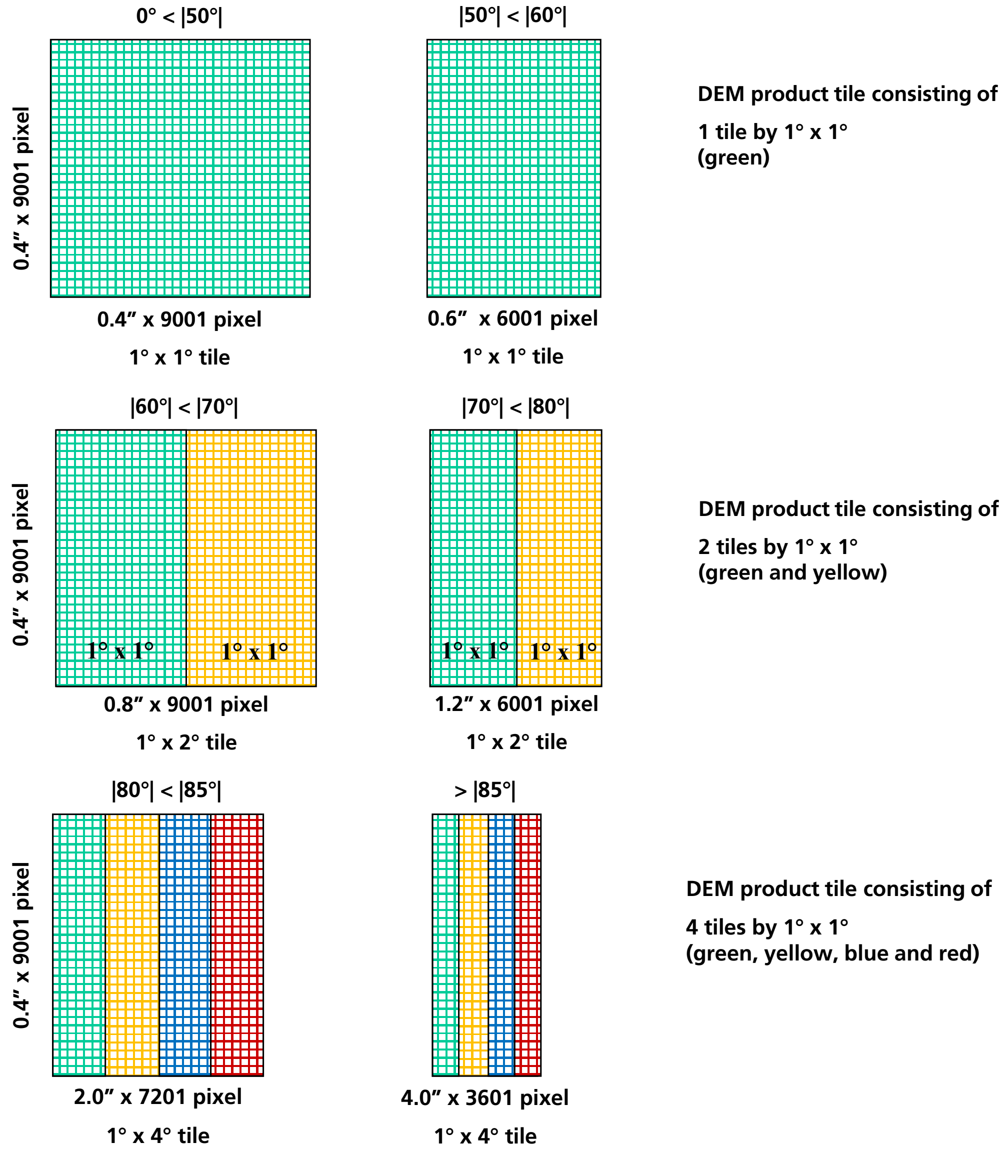

Figure 15: Latitude dependent geographical file extent of TanDEM-X DEM tiles.

Zone	*Latitude North/South*	*Tile size latitude x longitude*	*Latitude pixel spacing*	*Longitude pixel spacing*	*Rows/ columns*	*Total size of TanDEM-X DEM product (approx. MB)*
I	**0° – 50°**	**1° x 1°**	0.4''	0.4'' (12.37m – 7.95m)	9001/9001	1310
II	**50° – 60°**		0.4''	0.6'' (11.92m – 9.28m)	9001/6001	980
III	**60° – 70°**	**1° x 2°**	0.4''	0.8'' (12.37m – 8.46m)	9001/9001	1310
IV	**70° – 80°**		0.4''	1.2'' (12.69m – 6.44m)	9001/6001	980
V	**80° – 85°**	**1° x 4°**	0.4''	2.0'' (10.74m - 5.39m)	9001/7201	1050
VI	**85° – 90°**		0.4''	4.0'' (< 10.78m)	9001/3601	525

Table 9: TanDEM-X DEM tile extent and file size depending on latitude zones including all information layers (without annotation or quicklooks).

4.5 Specifics of DEM Product Variants

4.5.1 TanDEM-X DEM reduced to 1-arcsecond and 3-arcseconds pixel spacing

The TanDEM-X DEM and TanDEM-X DEM 2020, are additionally available with a pixel spacing of 1-arcsecond and 3-arcseconds (Table 10). This represents an increase of the original pixel spacing by a factor 2.5 and 7.5, respectively. The latitude pixel spacing corresponds for the 1 arcsecond DEM to 30.92 meters at the equator and to 30.82 meters near the poles, for the 3 arcsecond DEM to 92.78 meters at the equator and to 92.48 meters near the poles.

The DEM values for the increased spacing are unweighted mean height values of the underlying higher resolution pixels. Partly contributing pixels are considered proportionately. Equivalent to the DEM, the reduced layers of the height error map (HEM) and the amplitudes (AMP, AM2) are also generated by averaging. Note: When averaging the HEM values an error reduction factor from error propagation of 2.5 (1-arcsecond) and 7.5 (3-arcseconds) is considered.

Auxiliary information layers like coverage mask (COV), layover and shadow mask (LSM), and the consistency mask (COM) are reduced by propagating the maximum value of the underlying pixels. The meaning of the respective values can be found in chapter 4.3.2.

The 1-arcsecond respectively 3-arcseconds water indication masks (WAM) are calculated by choosing the mode out of the underlying pixels, i.e. the most frequent value is propagated. In case of equal numbers, the maximum value is propagated.

The 3-arcsecond TanDEM-X DEM is available at DLR's EGP after registration [I27].

Zone	*Latitude*	*Latitude pixel spacing*	*Longitude pixel spacing*	*Latitude pixel spacing*	*Longitude pixel spacing*
		Reduced to 1-arcsec		**Reduced to 3-arcsec**	
I	0° – 50° North/South	1.0'' (30.92m @ equator - 30.82m near the poles)	1.0'' (30.92m – 19.88m)	3.0''(92.78m @ equator – 92.48m near the poles)	3.0'' (92.76m – 59.63m)
II	50° – 60° North/South	1.0''	1.5'' (29.81m – 23.19m)	3.0''	4.5'' (89.44m – 69.57m)
III	60° – 70° North/South	1.0''	2.0'' (30.92m – 21.15m)	3.0''	6.0'' (92.76m – 63.45m)
IV	70° – 80° North/South	1.0''	3.0'' (31.72m – 16.11m)	3.0''	9.0'' (95.18m – 48.33m)
V	80° – 85° North/South	1.0''	5.0'' (26.85m – 13.47m)	3.0''	15.0'' (80.54m – 40.42m)
VI	85° – 90° North/South	1.0''	10.0'' (26.95m – 0.00m)	3.0''	30.0'' (80.85m – 0.00m)

Table 10: Pixel spacing for TanDEM-X DEM in 1-arcsecond and 3-arcseconds spacing depending on latitude.

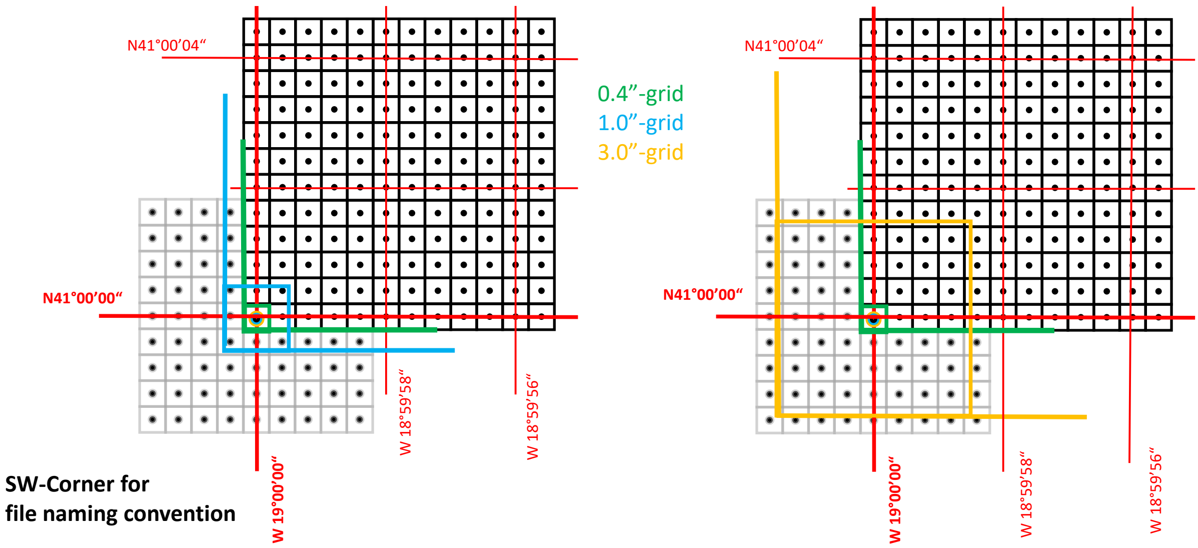

Figure 16: Grid definition and pixel extent for DEM tiles with different pixel spacings: black grid/green square: original 0.4-arcsecond grid, blue square: one 1-arcsecond pixel; yellow square: one 3-arcsecond pixel.

4.5.2 DEMs on special user-request

DEMs on special user-requests with an increased pixel spacing by a factor of 2 are possible and were realized for selected regions in form of High resolution DEMs (HDEMs), see Table 11.

Product	*Product ID*	*Latitude pixel spacing (arcsec)*	*Pixel spacing (meters)*	*Description*
HDEM	TDM1_HDEM	0.2 arcsec	approx. 6m	High resolution DEM produced by using HDEM-specific DEM acquisitions in order to improve the height error

Table 11: DEMs on special user request: HDEM.

Please note that in contrast to the TanDEM-X DEM standard products integer latitude and longitude coordinates are aligned to the borders of the pixels and no longer to the pixel centers. This has the advantage that the coverage of four HDEM pixels correspond exactly to one global DEM pixel. This different grid definition is displayed in Figure 16. The pixel spacing for HDEM is given in Table 12.

Zone	*Latitude*	*Tile size latitude x longitude*	*Latitude pixel spacing*	*Longitude pixel spacing*	*Rows/columns*
I	0° – 50° North/South	1° x 1°	0.2''	0.2''	18002/18002
II	50° – 60° North/South	1° x 1°	0.2''	0.3''	18002/12002
III	60° – 70° North/South	1° x 2°	0.2''	0.4''	18002/18002
IV	70° – 80° North/South	1° x 2°	0.2''	0.6''	18002/12002
V	80° – 85° North/South	1° x 4°	0.2''	1.0''	18002/14402
VI	85° – 90° North/South	1° x 4°	0.2''	2.0''	18002/7202

Table 12: Pixel spacing depending on latitude for HDEM.

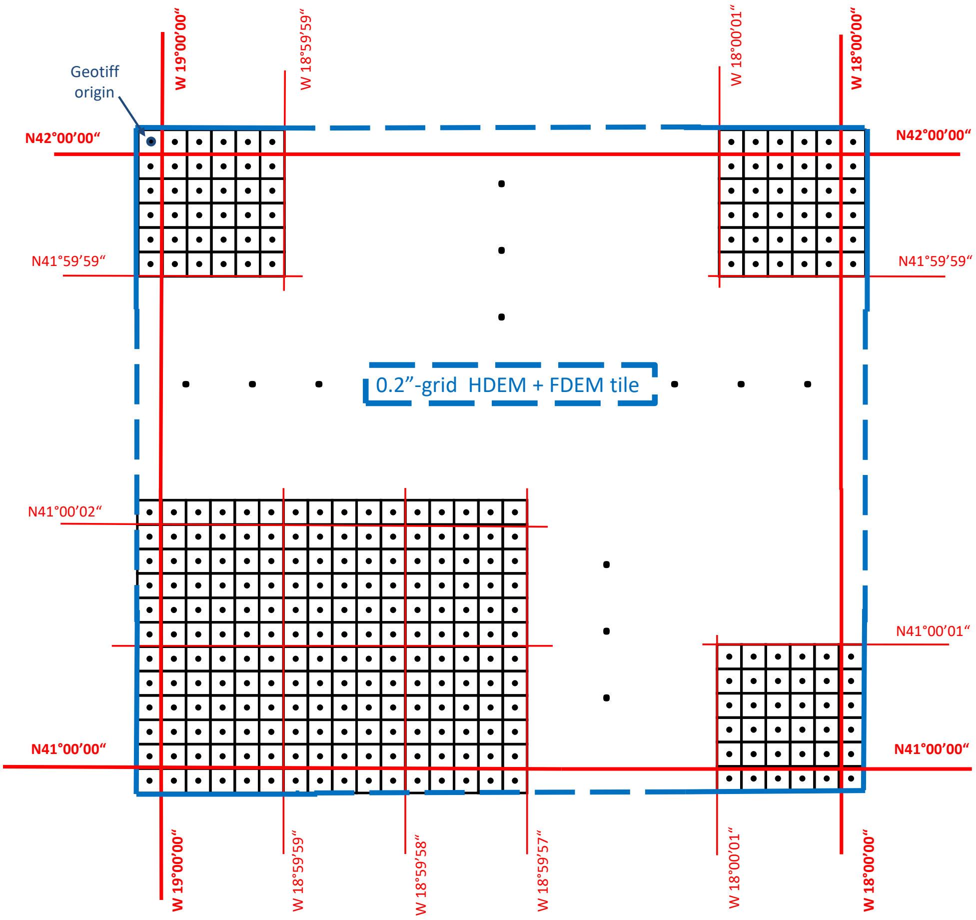

Figure 17: Grid definition for HDEM tiles. In contrast to the TanDEM-X DEM standard products the coordinates of integer latitudes and longitudes are aligned to the borders of the pixels (e.g. see W19°00'00'', N41°00'00''). The tile extent is indicated by the blue bounding box.

4.5.2.1 **HDEM (High resolution DEM)**

Higher resolution DEMs were exclusively produced from dedicated TanDEM-X DEM acquisitions. The pixel spacing is also increased by a factor of 2 compared to the standard DEM products but an improved random height error could be realized. On the one hand by several dedicated HDEM-specific acquisitions acquired with low height of ambiguity, on the other hand by the new "delta-phase "phase-unwrapping approach [I18] within the ITP instead of the dual-(or multi-)baseline phase-unwrapping algorithm developed for the mission. Herein, the HDEM phase unwrapping is based on a locally edited version of the TanDEM-X DEM in 12m resolution to reduce the density and number of the interferometric fringes. For an optimal reduction of the random height error three to four coverages were planned. The performance goal was 0.8 meter random height accuracy (see Table 1) with an independent pixel spacing of about 0.2 arcseconds (Table 12). HDEMs were produced for 7 demonstration sites with in total 124 HDEM tiles [I19]. They are available at DLR's EGP with a vaild DEM proposal. Please note that no water detection based on the coherence was performed for the HDEM scenes.

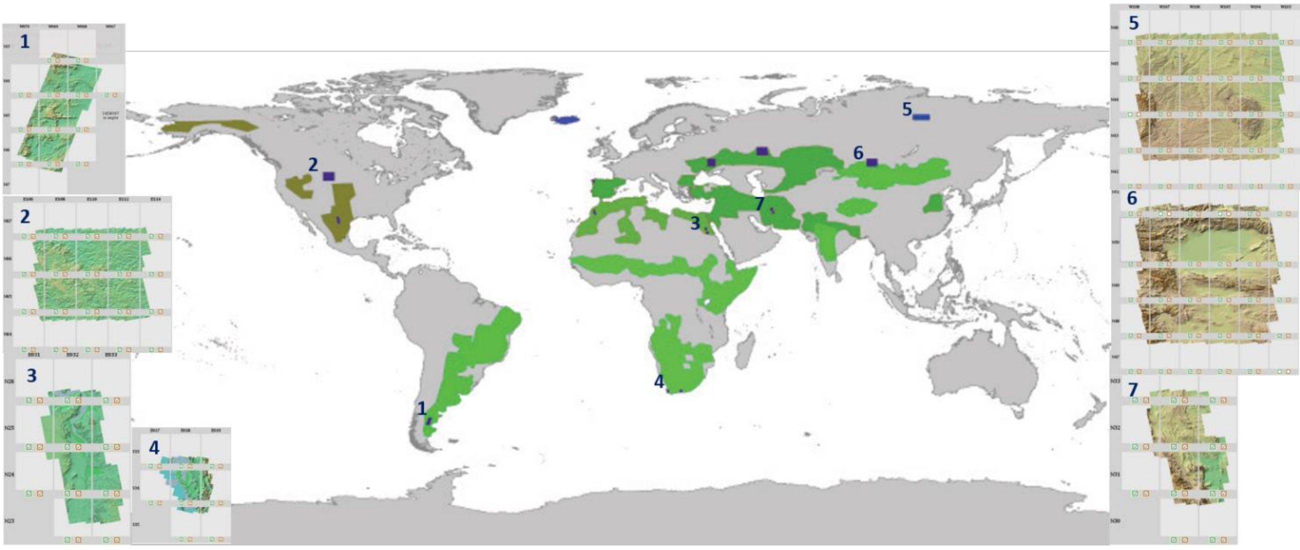

Figure 18: Realized HDEM demonstration test sites. Operationally available via scientific DEM proposal: 1: USA, 2: Argentina, 3 Egypt/Luxor, 4. Southafrica/Cape Town, 5. Russia, 6. Mongolia, 7. Iran.

4.5.3 Specifics of TanDEM-X DEM 2020

Compared to the TanDEM-X DEM, the new TanDEM-X DEM 2020 shows three main differences:

1. an independent and more up-to-date time span
2. an advanced phase unwrapping strategy and
3. a reduced number of coverages with an adopted acquisition plan.

The time span, the phase unwrapping approach "delta-phase" and the adopted acquisition plan are described in Chapter 4. Further TanDEM-X DEM 2020 Specifications are described in the following.

The TanDEM-X DEM 2020 follows the same product format specifications as the global TanDEM-X DEM [I1]. In support of user-friendliness, a layer for mean sea level elevations has been added (see Section 4.3.2.2). The TanDEM-X DEM, as well as the TanDEM-X DEM 2020, are additionally available with a pixel spacing of 1-arcsecond and 3-arcseconds. This represents an increase of the original pixel spacing by a factor 2.5 and 7.5, respectively.

The lack of several coverages affects the relative height error performance. A sophisticated acquisition scenario has been developed to maximize the performance – taking into account seasonal changes and specific properties of several regions. Yet, the random errors varies slightly over the swathes (in range) since a clapboard pattern is no longer available. Nevertheless, the TanDEM-X DEM 2020 was processed to the same pixel spacing as the first global DEM but using an adaptive filtering (more interferometric looks and different filter settings depending on the presence of azimuth ambiguities) applied at the benefit of a lower random height error. Most data have similar HoA values as the first global coverage (locally even better). Thus the relative height error performance is expected to be just slightly worse than the ones achieved for the first global TanDEM-X DEM (see Table 1), in many regions with more than one coverage even better.

However, deviations might be present with respect to product quality and completeness. Some known deviations are listed in the following:

- The relative height accuracy is different for the specific acquisition regions (indicated in the map Figure 1 and Table 1).
- In order to achieve the performance for the relative random height accuracy with mainly one coverage and with a pixel spacing of less than 12 meter, the resolution (and the interferometric looks) of the interferograms of the single scenes may exceed 12m (e.g. reaching 15m).

- A DEM layer with mean sea level heights was added for TanDEM-X DEM 2020 (see Sec. 4.4.2.2)
- Shadow and layover regions in difficult terrain are not filled with data from other viewing geometries.
- Errors in the edited reference DEM used for phase unwrapping support may result in local height discrepancies.
- Other limitations to the information layers (e.g. limited accuracy of the water mask) due to the reduced number of coverages.

A. Appendix: Product parameters

A.1.1. Overview of the XML structure

The following Figure gives an overview of the structure of the XML.

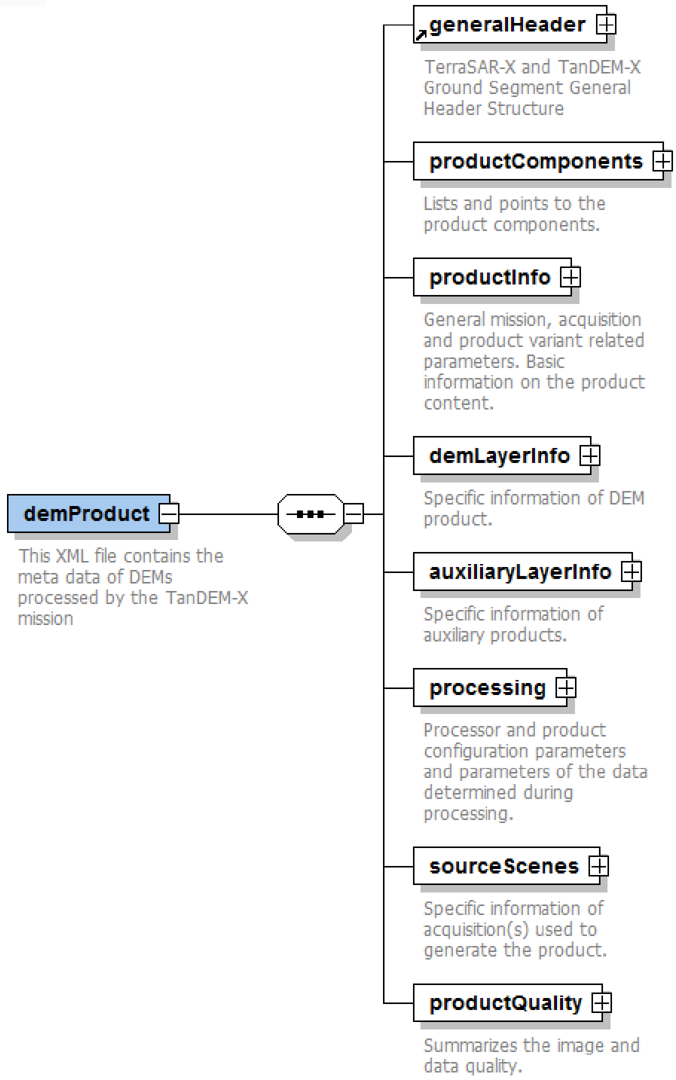

Figure 19: Overview of the XML structure

A.1.2. List of selected annotation parameters

In the Table 13 below, a selection of annotation parameters with their descriptions is provided. A complete annotation list of all XML parameters can be found in the XSD files attached to this pdf document.

generalHeader:	TerraSAR-X and TanDEM-X ground segment general header structure.
- generationSystem	Product generation software and version, e.g. MCP_MOS version 4.7
- generationTime	Product generation time
- revision	Product revision, e.g. PO_MOS_08
ProductComponents:	Lists and points to the product components.
ProductInfo:	General mission, acquisition and product variant related parameters. Basic information on the product content.
- generationInfo-> demTileIdentifier	Tile identifier, e.g. TDM1_IDEM_04_N42E014
- generationInfo-> demTileVersion	Tile version, e.g. 1, 2, 3, …
- generationInfo-> demTileStatus	Tile status, e.g. PRELIMINARY, COMPLETED, …
- acquisitionInfo-> lookDirection	Look direction(s) of contributing acquisitions: left, right, both
- acquisitionInfo-> orbitDirection	Orbit direction(s) of contributing acquisitions: ascending, descending, mixed
- productVariantInfo-> productType	Product type, i.e. DEM
- productVariantInfo-> productVariant	Product variant, e.g. DEM, HDEM, DEM2
- productVariantInfo-> resolutionVariant	Product resolution variant, e.g. 04 (= 0.4 arcsec), 10 (= 1.0 arcsec), 30 (= 3.0 arcsec)
- spatialCoverage	Spatial coverage description (bounding box, frame coordinates)
- altitudeCoverage	Altitude coverage description (min, max, mean height)
- temporalCoverage	Temporal coverage description (start/stop time)
- coverageCompleteness	Parameters of coverage completeness (e.g. percentage of valid DEM pixel)
demLayerInfo:	Specific information of DEM product.
- imageDataInfo-> pixelValueID	Text describing layer content (e.g. DIGITAL_ELEVATION_MODEL, RADAR_AMPLITUDE_MEAN, ...)
- imageDataInfo-> valueInvalidPixel	Invalid value, e.g. -32767.0, 0, ...
- imageDataInfo-> imageRaster	Size and spacing of image layer (numberOfRows, numberOfColumns, rowSpacing, columnSpacing)
- imageDataInfo-> imageDataStatistics	Statistics of image layer (e.g. min, max, mean values)

processing:	Processor and product configuration parameters and parameters of the data determined during processing.
- numberOfUsedAcquisitions	Total number of acquisitions used to generate the product
- numberOfUsedScenes	Total number of RawDEM scenes used to generate the product
- minNumberCoverages	Minimum number of acquisitions used to generate a height value
- maxNumberCoverages	Maximum number of acquisitions used to generate a height value
- processingParameter -> bestResolutionOnGround	Best resolution on ground in meter
- processingParameter -> accessRegion	Flag to identify certain regions, e.g. GLOBAL, POLAR, ...
- processingParameter -> onTopMosaic	Acquisition(s) were added to a prior version of the product, e.g. additional acquisition(s) were mosaicked on top.
sourceScenes:	Specific information of acquisition(s) used to generate the product.
- acquisition-> acquisitionItemId	ID of acqusition, e.g. 1023456
- acquisition-> orbitDirection	Orbit direction, i.e. ascending, descending
- acquisition-> acquisitionStartTimeList-> acquisitionStartTime	Acquisition start time of scene
- acquisition-> incidenceAngleCenterList-> incidenceAngleCenter	Incidence angle center of scene
- acquisition-> heightOfAmbiguityList-> heightOfAmbiguity	Height of ambiguity of scene
- acquisition-> sceneCornerCoordList-> sceneCornerCoord	Corner coordinates of scene
productQuality:	Summarizes the image and data quality.
- qualityInspection	MCP processor internal quality control result, e.g. APPROVED, LIMITED_APPROVAL, ...
- qualityRemark	MCP processor quality remark, e.g. tile_is_ok, small_PU_error; see Sec. 5.2.2
- availabilityOfSrtm	Flag indicating the availability of SRTM data for validation
- diffToSrtmMean	Mean difference to SRTM C-Band DEM (if applicable)

- diffToSrtmStd	Standard deviation of difference to SRTM C-Band DEM (if applicable)
- diffToSrtm90Percent	90 Percent of absolute height differences (SRTM C-Band DEM minus diffToSrtmMean) are within this value (if applicable)
- availabilityOfIcesat	Flag indicating the availability of ICESat data for validation
- diffToIcesatMean	Mean difference to ICESat validation points (if applicable)
- diffToIcesat90Percent	90 Percent of absolute height differences (ICESat validation points minus diffToIcesatMean) are within this value (if applicable)
- diffToIcesatStd	Standard deviation of difference to ICESat validation points (if applicable)
- numberValidationPointsIcesat	Number of ICESat validation points (if applicable)
-	
-	
-	

Table 13: List of selected annotation parameters.

A.1.3. Main DEM product quality parameters

At a first glance, the quality of the DEM product can be characterized by the three parameters: demTileStatus, qualityInspection and qualityRemark.

A.1.4. DEM tile status and quality inspection status

For each tile a demTileStatus is provided. The status flag 'COMPLETED' indicates that all TanDEM-X acquisitions were used for the DEM mosaic. The status 'PRELIMINARY' indicates that future TanDEM-X acquisitions may also contribute to the DEM mosaic.

In addition, a qualityInspection status will be given after an operator inspection of the DEM tile. The following quality status flags are available:

- APPROVED
- LIMITED_APPROVAL
- NOT_APPROVED

For the TanDEM-X DEM the quality status flag was set in a very conservative way, i.e. in case of inconsistencies of even small spatial extent, the tile status qualityInspection was set to LIMITED_APPROVAL. DEM tiles with more severe quality issues receive the status flag NOT_APPROVED. Table 14 provides a list-describing under which condition a certain qualityInspection status is set by the operator.

DEM tile remark

In addition to the quality inspection a bundle of different remarks given by the operator can be annotated to the product. The qualityRemark can be composed of several elements:

[height_error_prefix,prefix_exception,operator_intervention,]**mainRemark**

prefix for large absolute and/or relative height error

height_error_prefix (*optional*):	“large_absolute _height_error”, „large_relative_height_error”,
prefix_exception (*optional*):	„no_reliable_reference”, “volume_decorrelation”
operator_intervention *(optional):*	„operator_intervention,ice”, “operator_intervention,water”
mainRemark (*mandatory*):	„DEM_gap”, “large_pu_error”, “small_pu_error”, “cloud”, “voids_over_land”, “miscellaneous”, “tile_is_ok”

The main component of the qualityRemark is represented by the mainRemark. This mainRemark is mandatory and always set. The prefix part of the qualityRemark is optional and provides information about increased absolute and/or relative height errors and is related to the accuracy criteria negotiated with the commercial partner Airbus Defence and Space. The calculations for the relative and absolute height error refer to vaild land pixels. Water is masked out for these calculations by a maximum water mask obtained from the WAM of the DEM tile.

For TanDEM-X DEM 2020, the setting of the tile status qualityInspection has been relaxed. Only two mainRemarks were assigned. The mainRemark “unremarkable” is selected for none or minor effects whilst the status qualityInspection was set to APPROVED. The mainRemark “erroneous” was only selected for larger or severe effects and the tile status qualityInspection was set to LIMITED_APPROVAL or NOT_APPROVED for these cases.

mainRemark (TanDEM-X DEM 2020):	“unremarkable“ „erroneous“

In the following the components of the qualityRemarks are listed, sorted by severity.

Remark	*Description*	*qualityInspection*

mainRemark		
DEM_gap	land coverage is missing, due to missing DEM acquisitions: effected area is larger than 1.000 km²	NOT_APPROVED
large_pu_error	large PU-errors remain: depending on severity resp. effected area is larger than 1.000 km²	NOT_APPROVED
voids_over_land	voids over land remain, e.g. caused by incoherence: effected area is larger than 1.000 km²	NOT_APPROVED
<mainRemark>	several effects sum up: effected area larger than 1.000 km². The most grave effect is annotated as mainRemark.	NOT_APPROVED
DEM_gap	land coverage is missing due to missing DEM acquisitions: effected area is smaller than 1.000 km²	LIMITED_APPROVAL
large_pu_error	large PU-errors remain: effected area is smaller than 1.000 km²	LIMITED_APPROVAL
small_pu_error	small PU-errors remain (no indication of size given)	LIMITED_APPROVAL
cloud	cloud induced effects are visible in tile	LIMITED_APPROVAL
voids_over_land	voids over land remain, e.g. caused by incoherence: effected area is smaller than 1.000 km²	LIMITED_APPROVAL
miscellaneous	other effects, e.g. effects caused by different years or seasons	LIMITED_APPROVAL
tile_is_ok	tile is okay, nothing to be noted	APPROVED
unremarkable	tile is okay, nothing to be noted (for TanDEM-X DEM 2020 only)	APPROVED
erroneous	severe effects are present (for TanDEM-X DEM 2020 only)	LIMITED_APPROVAL/ NOT_APPROVED
height_error_prefix		
large_absolute _height_error	The 90% absolute height error exceeds the threshold of 10 m (given in Table 1) measured to ICESat validation points	NOT_APPROVED
	This evaluation is overruled by the following exceptional cases: "large_absolute_height_error,**no_reliable_reference"**: less than 200 validation points available "large_absolute_height_error,**volume_decorrelation"**: more than half of the land area of the tile are presumably covered by forest or snow "large_relative_height_error,**operator_intervention,[ice,water]"**: **ice**: statistic not meaningful, because of ICESat points over ice (ice was interpreted as land) **water**: statistic not meaningful, because of ICESat points over water	 APPROVED LIMITED_APPROVAL APPROVED APPROVED
large_relative_height_error	The 90% relative height error exceeds the thresholds given in Table 1	NOT_APPROVED

	This evaluation is overruled by the following exceptional cases:	
	"large_relative_height_error**,no_reliable_reference"**: DEM tile contains less than 0.1% valid land pixel for statistic calculations	APPROVED
	"large_relative_height_error**,volume_decorrelation"**: more than half of the land area of the tile are presumably covered by forest or snow	LIMITED_APPROVAL
	"large_relative_height_error**,operator_intervention,[ice,water]"**:	
	ice: statistic not meaningful, because ice was interpreted as land	APPROVED
	water: statistic not meaningful, because water was interpreted as land	APPROVED

Table 14: List of qualityRemark components.

TanDEM-X DEM

The qualityInspection status **APPROVED** is set, if **no effects** in the DEM tile are present. Correspondingly, the mainRemark "**tile_is_ok**" is assigned.

The qualityInspection status **LIMITED_APPROVAL** is set, if some minor effects are present, and the relevant mainRemark is assigned. In case of several effects, the most severe effect according to the order of Table 14 is assigned.

The qualityInspection status **NOT_APPROVED** is set, if the effected area is larger than approx. 1.000 km^2.

The height_error_prefix is set in front of the mainRemark when the 90% relative height error or the 90% absolute height error limit is exceeded. In this case, the qualityRemark changes to e.g. "large_relative_height_error,tile_is_ok" with the qualityInspection status NOT_APPROVED.

Due to the fact that the relative height error calculations are carried out separately for each DEM product variant (0.4", 1.0" and 3.0" pixel spacing), it is possible that the qualityInspection status and qualityRemark differs for a certain tile for each variant.

TanDEM-X DEM 2020

The qualityInspection status **APPROVED** is set, if **no or only minor effects** in the DEM tile are present. Then, the mainRemark "**unremarkable**" is assigned.

The qualityInspection status **LIMITED_APPROVAL** is set, if intermediate or larger effects are present, and the mainRemark "**erroneous**" is assigned.

The qualityInspection status **NOT_APPROVED** is set, if the effected area is particularly large and/or the effect is particularly severe.

The **height_error_prefix** is set in front of the mainRemark when the 90% relative height error or the 90% absolute height error limit is exceeded. In this case, the qualityInspection status changes to **LIMITED_APPROVAL**. In cases of severe DEM errors, **NOT_APPROVED** is assigned.

Due to the fact that the relative height error calculations are carried out seperatley for each DEM product variant (0.4", 1.0" and 3.0" pixel spacing), it is possible that the qualityInspection status and qualityRemark differs for a certain tile for each variant.

B. APPENDIX: PRODUCT CHANGE LOG

B.1.1. Change log for XML structure

Note that the XML schema definition as of version 2.1 is compatible with higher XML schema definitions (like for version 2.2, 2.3 and 2.4). Please ensure to use the latest XML scheme, which is attached in the latest version of this document.

- New in version 2.4 (demProduct.xsd): updated documentation of "productVariant", changed maxOccurs of "demLayerInfo" to value 2
- New in version 2.3: XSD contains more precise annotations

  Clarification: The parameters diffToSrtm90Percent and diffToIcesat90Percent represent mean-adjusted 90-quantile measures, see Table 13.
- New in version 2.2: XSD contains more precise format definitions
- Since XML schema definition version 2.1 (first version for DEM products) the following parameters are new in the XML:
  - changed XML node coverageCompleteness into coverageCompletenessInfo
  - diffToSrtm90Percent new parameter (optional, if applicable) since PO_MOS_16
  - diffToIcesat90Percent new parameter (optional, if applicable) since OP_MOS_03
- Note the XML schema definition 2.0 (for IDEM) is not compatible with XML schema definition 2.1 or higher.

B.1.2. Change log for operational DEM generation

Note: The change log listed here refers to changes in the parameter and the raster file calculations. There may be more recent revisions annotated in the product due to ongoing software improvements.

- Revision PO_MOS_16 activated at 02.09.2013

  - Smoothing factor for HEM resolution reduction from 0.4" to 1.0" and 3.0" is introduced.

  - Interpolation Mask (IPM) is omitted.

  - calculation of new statistic parameter for XML: 90 percent value of the mean-adjusted difference TanDEM-X DEM minus SRTM (diffToSrtm90Percent)
- Revision OP_MOS_01 activated at 18.10.2013:

  - new DEM QL with consistent scale

  - Method for WAM mosaicking is set to maximum method (the highest number of water counts is propagated)

  - Invalid DEM values at raw DEM borders are now correctly handled (no more artefacts from raw DEM borders visible)
- Revision OP_MOS_03 activated at 08.01.2014:

  - Raw DEMs with low quality (high height offset, etc…) are only used for gap filling (backup DEMs).

  - Optimization of mosaicking thresholds for handling of inconsistent height values (especially in forested areas)

  - calculation of new statistic parameter for XML: 90 percent value of the mean-adjusted difference TanDEM-X DEM minus ICESat (diffToIcesat90Percent) (Parameter was tailed also for the revisions OP_MOS_01 and PO_MOS_16)
- Revision OP_MOS_11 activated at 10.11.2015:

  - Corrected calculation of XML parameter coveragePotentialLand and coveragePotentialWater over desert areas (desert identified by MODIS) (MCP_MOS_V5.57)

- Revision OP_MOS_12 activated at 19.04.2016:

  - Updates for RawDEM handling near the pole and close to dateline

  - Note that due to the one-pixel overlap at the southern tile border the S90 products will contain coordinates below -90 degree: in the kml containing the outline (e.g. TDM1_DEM__04_S90W180.kml) and in the metadata XML (e.g. TDM1_DEM__04_S90W180.xml).

- Revision OP_MOS_13 activated at 10.07.2017

  - Updates for HDEM generation

- Revision OP_MOS_17 activated at 21.10.2024

  - Updates for TanDEM-X DEM 2020 generation -